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On-farm feeding and feed management in aquaculture

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Left top to bottom: Feeding grow-out striped catfish (*Pangasianodon hypophthalmus*) with farm-made aquafeed from a feeding station, Mekong delta, Viet Nam (courtesy of FAO/T.P. Nguyen). A farmer feeding black tiger shrimp (*Penaeus monodon*) with commercially produced pelleted feed from levee during first month of rearing (courtesy of FAO/Umesh N. Ramasawamy).
Right: Feed distribution using automatic feeder for cage culture of Atlantic salmon (*Salmo salar*) near Bodo in Norway (courtesy of Trevor Telfer).

Cover design:
Mohammad R. Hasan

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Preparation of this document

This technical paper was prepared by a group of experts under the leadership of Dr Mohammad R. Hasan as a part of the Food and Agriculture Organization of the United Nations (FAO) Aquaculture Service's (FIRA) ongoing regular work programme on "Studies, reviews, guidelines and manuals on use of feed and nutrient in sustainable aquaculture development", under the organizational output "Aquaculture practices and technologies that comply with the Code of Conduct for Responsible Fisheries (CCRF) are developed and promoted".

This technical paper reviews the current status of on-farm feeding and feed management in aquaculture. It contains a) ten case studies on feeding and feed management practices carried out in seven selected countries of Asia (i.e., Bangladesh, China, India, Thailand, Viet Nam) and Africa (i.e., Egypt, Ghana) for eight species belonging to four major farmed species of freshwater finfish and shellfish: shrimp and prawns, Nile tilapia, striped catfish and Indian major carps; b) an analysis of the findings of these ten case studies and a case study for Indian major carps in India (published separately[1]); c) ten invited specialist reviews on feed management practices from regional and global perspectives and d) an overview of the current status of feed management practices with information drawn from the case studies, the invited reviews and other related publications. In addition, a targeted workshop entitled "On-farm feeding and feed management in aquaculture" was convened in Manila, the Philippines, from 13–15 September 2010 where all the above case study reports, analysis of case studies and invited review papers were presented. The workshop was organized by the Fisheries and Aquaculture Department Aquaculture Service (FIRA) and was hosted by the Southeast Asian Fisheries Development Center Aquaculture Department (SEAFDEC/AQD), Iloilo, the Philippines. The report of the workshop was published as a FAO Fisheries Report (www.fao.org/docrep/013/i1915e/i1915e00.pdf).

Before editorial work, the manuscripts in this technical paper were reviewed for technical content, FAO house style and linguistic quality by Dr Richard Arthur for the invited reviews and synthesis paper and by Dr Thomas Shipton for the case studies. For consistency and conformity, scientific and English common names of fish species were used from FishBase (www.fishbase.org/search.php).

Much gratitude is due to the authors of the invited reviews and case studies, who faced an enormous task and showed tremendous patience with the editors. Ms Tina Farmer and Ms Marianne Guyonnet are acknowledged for their assistance in quality control and FAO house style. Mr Koen Ivens prepared the layout design for printing, and Ms Danielle Rizcallah provided miscellaneous assistance. The publishing and distribution of the document were undertaken by FAO, Rome. Finally, Jiansan Jia, Chief of the Aquaculture Branch of the FAO Fisheries and Aquaculture Department is acknowledged for providing the necessary support, advice and insight to initiate the study and to complete the publication.

This publication is organized in three sections: a) Overview and Synthesis, b) Case Studies, and c) Invited Reviews. The publication is printed with the first section "overview and synthesis" while the whole volume is available on a CD–ROM accompanying the printed part of this publication.

[1] Ramakrishna, R., Shipton, T. & Hasan, M.R. 2013. Feeding and feed management of Indian major carps in Andhra Pradesh, India. FAO Fisheries and Aquaculture Technical Paper No. 578. Rome, FAO. 90 pp.

Abstract

This technical paper provides a comprehensive review of on-farm feeding and feed management practices in aquaculture. It comprises of a) ten case studies on feeding and feed management practices carried out in seven selected countries of Asia and Africa for eight species that belong to four major farmed species of freshwater finfish and shellfish; b) an analysis of the findings of the above ten case studies and a separately published case study for Indian major carps carried out in India; c) ten invited specialist reviews on feed management practices from regional and global perspectives; and d) an overview of the current status of feed management practices. The country-specific case studies were carried out for Nile tilapia (*Oreochromis niloticus*) in China, Thailand, the Philippines, Egypt and Ghana; Indian major carps [rohu (*Labeo rohita*), catla (*Catla catla*) and mrigal (*Cirrhinus cirrhosus*)] in India and Bangladesh, giant river prawns (*Macrobrachium rosenbergii*) in Bangladesh, striped catfish (*Pangasianodon hypophthalmus*) and whiteleg shrimp (*Litopenaeus vannamei*) in Viet Nam and black tiger shrimp (*Penaeus monodon*) in India. The broad thematic areas that were addressed in these case studies and invited reviews are: i) current feed types (including fertilizers) and their use in semi-intensive and intensive farming systems; ii) on-farm feed production and management; iii) feeding and feed management strategies, feed procurement, transportation and storage; iv) environmental, economic, regulatory and legal frameworks of feeding and feed management practices; and iv) identification of research needs. Based on the information presented in the eleven case studies, ten specialist reviews and from other relevant publications, an overview paper presents concluding remarks and recommendations on some of the major issues and constraints in optimizing feed production, use and management.

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On-farm feeding and feed management in aquaculture.
FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 67 pp.
Includes a CD–ROM containing the full document (585 pp.).

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Abbreviations and acronyms

ABW	average body weight
ADB	Asian Development Bank
AI	active ingredient
AIT	Asian Institute of Technology
ARI	Animal Research Institute, Ghana
BAFPS	Bureau of Agriculture and Fisheries Products Standards, Philippines
BAI	Bureau of Animal Industries, Philippines
BCR	benefit-cost ratio
BDT	Bangladesh taka
BFAR	Bureau of Fisheries and Aquatic Resources, Philippines
BFDC	Bangladesh Fisheries Development Corporation
BMP	better management practices
BOD	biochemical oxygen demand
BW	brackishwater
BWD	body weight per day
C	carbon
CAAC	Certification and Accreditation Administration of China
CAA	Coastal Aquaculture Authority, India
CAAP	concentrated aquatic animal production systems
CCRF	Code of Conduct for Responsible Fisheries
CFU	colony forming units
CIBA	Central Institute of Brackishwater Aquaculture, India
CIFA	Central Institute of Freshwater Aquaculture, India
CIFE	Central Institute of Fishery Education, India
COD	chemical oxygen demand
CP	crude protein
CSIR	Council for Scientific and Industrial Research, Ghana
CSIRO	Commonwealth Scientific and Industrial Research Organization, India
DAP	diammonium phosphate
DM	dry matter
DOC	days of culture
DoF	Directorate of Fisheries
EAN-UCC	European article numbering-uniform code council
ECAA	Extension Service Centre for Agriculture and Aquaculture, Viet Nam
EFS	extensive farming system
EIA	Export Inspection Agencies, India
EIC	Export Inspection Council, India
EM fungi	Ectomycorrhizal fungi
FAO	Food and Agriculture Organization of the United Nations
FaST	freshwater aquaculture centre selected tilapia
FBMA	Fisheries Bureau of Ministry of Agriculture, China
FCR	feed conversion ratio
FHS-BFAR	Fish Health Section of the Bureau of Fisheries and Aquatic Resources
FW	freshwater

g	gramme
GAFRD	General Authority for Fisheries Resources Development, Egypt
GAP	good aquaculture practices
GDP	gross domestic product
GIFT	genetically improved farmed tilapia
GST	genomar supreme tilapia
ha	hectare
HACCP	hazard analysis and critical control points
hCG	human chorionic gonadotropin
hrs	hours
ICAR	Indian Council of Agriculture Research
ICS	internal control system
IFN	international feed number
IMC	Indian major carps
INR	Indian rupee
IU	international units
kg	kilogramme
m	metre
MA	Ministry of Agriculture, China
MALR	Ministry of Agriculture and Land Reclamation, Egypt
MAR	Ministry of Agriculture and Rural Development, Viet Nam
MBV	Monodon baculovirus
MDCP	monodicalcium phosphate
MEFS	modified extensive farming system
mg	milligramme
mm	millimetre
MoFA	Ministry of Food and Agriculture, Ghana
MoFI	Ministry of Fisheries, Viet Nam
MP	muriate of potash
MPEDA	Marine Products Export Development Authority, India
MRP	maximum retail price
MSL	mean sea level
MT	million tonnes
mu	unit used for land measurement in China (1 mu = 666.7 square meters)
N	nitrogen
NACA	Network of Aquaculture Centres in Asia-Pacific
NaCSA	National Centre for Sustainable Aquaculture, India
NAFIQUAVED	National Fisheries Quality Assurance and Veterinary Directorate, Viet Nam
NFDB	National Fisheries Development Board, India
NFE	nitrogen free extracts
NPK	nitrogen, phosphorus and potassium
NR	net return
OM	organic matter
P	phosphorus
PG	pituitary gland
PL	postlarvae
ppm	parts per million
ppt	parts per thousand
RGCA	Rajiv Gandhi Centre for Aquaculture, India
RMA	rapid market appraisal
SEAFDEC	Southeast Asian Fisheries Development Center

SEERAD	Scottish Executive Environment and Rural Affairs Department
SIFS	semi-intensive farming systems
SIS	small indigenous fish species
SPF	specific-pathogen-free
SSP	single superphosphate
t	temperature
TBCAPMPA	Tilapia Branch, China Aquatic Products Marketing and Processing Association
TC	total costs
TFC	total fixed costs
TFS	traditional farming system
TGR	total gross revenue
TP	triple phosphate
TSP	triple super phosphate
TVC	total variable costs
US$	United States dollar
USAID	United Sates Agency for International Development
VASEP	Vietnam Association of Seafood Exporters & Producers
VAT	value added tax
WHO	World Health Organization
WLS	whiteleg shrimp
WRI	Water Research Institute, Ghana
WSSV	white spot syndrome virus
WWF	World Wildlife Fund
YHV	yellow head virus

SECTION A
OVERVIEW AND SYNTHESIS

An overview of the current status of feed management practices

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Shipton, T.A. and Hasan, M.R. 2013. An overview of the current status of feed management practices. *In* M.R. Hasan and M.B. New, eds. *On-farm feeding and feed management in aquaculture.* FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. pp. 3–20.

ABSTRACT

This paper presents an overview of the current status of feed production and on-farm feed management practices. It reviews some of the major issues and constraints in optimizing feeds and on-farm feed management practices. The analysis is based on the findings of the country- and species-specific case studies, regional, and specialist subject reviews that are presented in this technical paper. Providing farmers with well-balanced feed at cost-effective prices is a prerequisite to profitable production. Formulation issues, and in particular the provision of species-specific feeds that address the nutritional requirements of the different life stages of the farmed animal (larval, fry, grower, finisher and broodstock) remain important topics for both commercial and farm-made feed production sectors. Much of the aquafeeds used in Asia and Africa are either produced on-farm or by small-scale semi-commercial feed manufacturers, and improvements to the quality and preparation of these feeds are likely to bring about improved productivity and cost savings. The small-scale production sector is currently constrained by a number of factors including inadequate access to finance, a lack of technical innovations, an absence of feed formulation and processing knowledge, and training. The potential to develop public-private partnerships with farmer groups or associations to share resources and improve access to improved manufacturing capacity should be considered. The majority of the case studies revealed that farmers across many countries and sectors were unaware of the importance of appropriate feed handling and storage techniques. The importance of feed management practices in optimizing production parameters needs to be conveyed to farmers. The use and efficacy of automated feeding systems needs to be established, and the use of feed tables, feed and production records needs to be promoted. Farmers need to be provided with simple tools to monitor farm production indices (e.g. feed conversion efficiency and growth rate) and training on how to take corrective actions. In extensive and semi-intensive production systems, there is a need to establish the qualitative and quantitative relationships between natural pond productivity and the impact that the use of supplemental and farm-made feeds have on nutrient cycling and

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retention in the farmed species. Developing a better understanding of these dynamics is central to optimizing feed formulations and reducing feed costs. The implications of feed type, formulation and feed management practices on the environmental footprint and economics of the farming operation are important issues that farmers need to take into consideration when planning their farming activities. If farmers understand and can quantify the economic interrelationships between feed type and costs, performance and feed management, they can significantly improve their profitability. Economic tools for this purpose to assist farmers need to be developed. Poor regulatory control and a lack of standards throughout the aquafeed value chain are constraints to feed supply, quality and use. Appropriate aquafeed policy, regulatory frameworks, and feed standards need to be developed in those countries that do not already have them, and institutional capacity needs to be strengthened in those agencies responsible for monitoring and compliance. Training and the dissemination of information to farmers, particularly small-scale farmers that have limited access to the latest technological and management developments, are issues that need to be addressed. Weak extension and information dissemination networks result in low adoption rates of new feed production technologies and management practices. Consideration should be given to promoting programs that use the local media to provide farmers with extension messages, including, amongst others, up-to-date feed ingredient availability, quality, price and supplier information, feed formulation and ingredient inclusion rates.

1. INTRODUCTION

In semi-intensive and intensive aquaculture systems, feed costs typically account for between 40 and 60 percent of production costs (De Silva and Hasan, 2007). In order to ensure profitability, it is imperative that farmers have access to good quality feeds at reasonable prices, and that they optimize their feed use by instituting appropriate on-farm feed management practices. This paper presents an overview of the current status of feed production and on-farm feed management practices, and provides a review of some of the major issues and constraints to optimizing them. The analysis is based on the findings of the species-specific country case studies, regional reviews, and specialist subject reviews that are presented in this technical paper.

These case studies and regional reviews focused on feed and feed management practices for Nile tilapia (*Oreochromis niloticus*) in China, Egypt, Ghana, the Philippines, Thailand, and sub-Saharan Africa, the Indian major carps (*Catla catla, Labeo rohita, Cirrhinus cirrhosus*) in Bangladesh and India, striped catfish (*Pangasianodon hypophthalmus*) in Viet Nam, North African catfish (*Clarias gariepinus*) in sub-Saharan Africa, whiteleg shrimp (*Litopenaeus vannamei*) in Viet Nam, black tiger shrimp (*Penaeus monodon*) in India and giant river prawns (*Macrobrachium rosenbergii*) in Bangladesh. The analysis also draws on selected reviews that focused on specific aspects of feed management, including environmental, economic, regulatory and manufacturing perspectives. Finally, it considers the outcomes of an FAO Expert Workshop on on-farm feed and feed management in aquaculture that was held in Manila, the Philippines, on the 13–15 September 2010 (FAO, 2010)[2].

2. SYNOPTIC REVIEW OF FARM-MADE AND COMMERCIAL FEED USE

As feed represents one of the highest operating costs in aquaculture systems (Hasan, 2007; Hasan *et al.*, 2007), feed choice and feed management practices have a significant impact on the economic performance of a production system. The type and value of feed inputs that farmers select is dependent upon a number of factors including

[2] http://www.fao.org/docrep/013/i1915e/i1915e00.pdf

the market (local, export) and the value of the fish, the financial resources available to the farmer, the species, the culture system and intensity of production. In general, inputs for low-value species that are grown for local consumption are usually limited to fertilizers, farm-made feeds or locally produced small-scale commercial feeds comprising one or more ingredient sources. Examples of these systems would include the Indian major carps cultured under extensive or semi–intensive conditions in India and Bangladesh (Ramakrishna, Shipton and Hasan, 2012; Sarder, 2013). In contrast, commercially manufactured pelleted feed inputs are used for high-value species that are cultured in intensive systems. Examples would include the salmonids in Europe and the Americas (Kaushik, 2013), and, increasingly, the high-value marine finfish (e.g. groupers, barramundi and snappers) that are increasingly produced across southeast Asia (Hasan, 2012a).

Rising competition for land and water resources is increasing pressures to improve productively through intensification. A move towards intensification of farming systems requires the adoption nutritionally complete feeds and is increasing the demand for both farm-made and commercially produced feeds (De Silva and Hasan, 2007; Rana, Siriwardena and Hasan, 2009). The case studies revealed this gradual shift towards intensification. For example in Egypt, the intensification of pond culture practices for Nile tilapia (*Oreochromis niloticus*) and the adoption of intensive cage culture technology have manifested as increased demand for commercially manufactured feeds, which now account for 60 percent and 100 percent of the feed used in these sectors respectively. This increase in demand has seen commercial feed manufacturing capacity in the country grow from 20 000 tonnes/annum in 1999 to 420 000 tonnes/annum in 2010 (El-Sayed, 2013). Likewise, a move towards intensification in black tiger shrimp (*Penaeus monodon*) production in India (Ramaswamy Mohan and Metian, 2013), Nile tilapia (*Oreochromis niloticus*) in the Philippines (Romana-Eguia, Laron and Catacutan, 2013), and striped catfish (*Pangasianodon hypophthalmus*) in Viet Nam (Nguyen, 2013) have also resulted in increases in the demand for commercially manufactured feeds.

Commercially manufactured feeds were reported to be available in all eight countries (Bangladesh, China, Egypt, Ghana, India, the Philippines, Thailand, and Viet Nam) where case studies were conducted and, with the exception of Ghana, all the countries reported commercial manufacturing capacity. Hecht (2007) noted that locally produced commercially manufactured feeds were only available in five sub-Saharan countries indicating that, in contrast with other producer regions (Europe, Asia and the Americas), sub-Saharan Africa generally lacks access to locally manufacturing capacity, and primarily relies on farm-made feeds or imported commercially produced feeds.

While commercially manufactured feeds are usually formulated to satisfy the nutritional requirements of specific species and their life stages, farm-made feeds typically comprise simple ingredients that, depending on the culture systems, are fed as simple mixtures, doughs or compressed pellets. While the quality of the farm-made feeds is dependent upon the formulation applied, the quality and availability of ingredients and the manufacturing processes, they are generally more affordable than commercially manufactured feeds, and remain the primary feed source for many semi-intensive farmers. For resource poor farmers, the relatively low cost of farm-made feeds enable them to procure small amounts of feed at any one time, promoting affordability and enabling them to better manage their on-farm cash flows.

The intensification of farming systems and the concomitant growth in demand for good quality, cost-effective farm-made feeds makes them increasingly important to sustaining sectorial growth, and it has been noted that one of the ways to improve aquaculture production is to improve the quality of farm-made feeds (De Silva and Davy, 1992; De Silva and Hasan, 2007).

Some production sectors have already seen significant improvements to the quality of farm-made feeds. For example, farmers in Viet Nam that use farm-made feeds for striped catfish production have improved their feed formulations and manufacturing

techniques. Formulations now contain up to six ingredient sources, and the feeds are extruded to form semi-moist pellets with improved water stability (Nguyen, 2013). In Bangladesh, the development of farmer associations has improved farmers' access to information (e.g. formulations, ingredient supplies and costs), and enhances their buying power and access to production technologies. The associations enabled the farmers to negotiate better ingredient prices and purchase them in bulk; increasingly, these farmers also have access to small-scale commercial feed manufacturers that are willing to produce feed batches in relatively small quantities, thus providing a level of manufacturing technology and feed quality that would otherwise be unattainable (personal observation of the authors). In this regard, the potential to promote public/private partnerships between small-scale feed manufacturers and farmers/farmer associations as a mechanism to improve access to cost-effective quality feeds needs to be investigated further.

3. FEED MANAGEMENT – ISSUES AND CONSTRAINTS

3.1 Feed production and handling

3.1.1 Feed formulation

Providing farmers with nutritionally balanced feeds is a prerequisite to cost-effective production. Formulation issues, in particular the provision of species-specific feeds that address the nutritional requirements of the different life stages of the farmed animal (larval, fry, grower, finisher and broodstock) remain issues for both commercial and farm-made feed production sectors.

Many of the commercially manufactured formulations that are available to farmers are based on laboratory formulations using high quality ingredients; few are conducted under commercial farming conditions. Formulations based solely on laboratory experiments do not always translate well to commercial conditions, where lower quality feed ingredients and least-cost formulae are applied. Likewise, the formulations are not always supported by rigorous scientific research, are poorly formulated, and sold to farmers who may be unaware of the nutritional requirements of their farmed species. Hasan (2012a) cited this problem in the expanding marine finfish sector in Southeast Asia where farmers were being encouraged to use the same commercial formulation for barramundi (*Lates calcarifer*) and grouper culture – two species groups that have different nutritional requirements. Indeed, the use of inappropriate formulations was found to be a common problem across a wide number of sectors. For example tilapia farmers in China were reported to use commercial grow-out formulations that contained a higher level of dietary protein than required (MoA, 2005) and tilapia farmers in Thailand were reported regularly to use commercial grow-out feeds that were designed for catfish and carps (Bhujel, 2013). In Viet Nam, striped catfish farmers reported using grow-out feeds that contained protein levels that were sub-optimal for the larger size classes (Nguyen, 2013). Despite the availability of manufactured feeds designed for the whiteleg shrimp (*Penaeus vannamei*), farmers reported using feeds that were designed for black tiger shrimp (*Penaeus monodon*); these have a higher protein level than is required by the species (Hung and Quy, 2013). The use of poorly formulated feeds that fail to satisfy the nutritional requirements of the species and their various life stages will inevitably result in feed inefficiencies and raised production costs. Evidently there is a need to inform farmers, feed suppliers and unregulated feed manufacturers of the importance of selecting and supplying appropriate species and size-specific formulations.

Some commercial formulations designed for specific life stages (e.g. fry, fingerling and grower) are so similar in terms of their nutrient content as to be virtually indistinguishable. This raises a number of issues including the nutritional rationale behind the formulations, the relationship between the nutrient inclusion rates and cost

differentials, and the ability of the manufacturers to maintain such small differences reliably in the nutrient levels in the feed. Resolving these issues and ensuring that farmers are supplied with appropriate formulations at cost-effective prices should be viewed as a priority, and will without doubt improve the economic performance of the farming operations.

While a significant amount of research has been undertaken to establish the nutritional requirements of many of the species groups, much of this has not been communicated to the farmers producing farm-made feeds or to small-scale feed manufacturers. Evidently, many farmers producing farm-made feeds are often unaware of the nutrient requirements of their farmed species, notably dietary protein and energy levels and how these change over the production cycle (White, 2013). Formulations are often based on past experience (what the farmers themselves have found to work), feed ingredient availability and cost, and advice from other farmers and feed ingredient suppliers. For example in Thailand, tilapia farmers indicated that they lacked basic information that they could use as formulation templates (Bhujel, 2013). The provision of simple training manuals focusing on the nutritional requirements of the farmed species, the availability, quality, composition, and cost of local feed ingredient sources, and methods to formulate feeds that satisfy specific nutritional requirements would significantly improve the quality of their formulations; it would also improve the economic efficiency of their farming operations. Training and information dissemination requirements are addressed in detail in Section 3.6.

3.1.2 Manufacturing technologies

Much of the aquafeeds used in Asia and Africa are either produced on-farm or by small-scale semi-commercial feed manufacturers (De Silva and Hasan, 2007; Hecht, 2007). Improvements to the quality and preparation of on-farm feeds are likely to bring about improved productivity and cost savings (Hasan *et al.*, 2007). Notwithstanding the quality of the feed ingredients used and the formulations applied, the manufacturing processes and type of feed produced can significantly affect feed performance. While farmers generally recognize the need to use quality feed ingredients, they often appear unaware that feed processing has a significant effect on feed quality and utilization. For example in China many of the feed ingredients that are used in farm-made tilapia feeds are poorly milled and fail to conform to the feed process standards as outlined by the national feed guidelines (Liu *et al.*, 2013; MoA, 2005). Presenting feeds as simple dry or moist mixtures or as moist mixed feeds leads to much of the feed being dispersed in the water column, resulting in low ingestion rates and high economic feed conversion ratios (eFCR). Feed efficiencies can be improved by encouraging farmers to use simple extruders and compressing their feed ingredients into dry pellets. Likewise, improving milling and the binding characteristics of the pellets reduces the amount of fines, improves pellet hardness and water stability, improves eFCR, and results in cost savings to the farmer (Rana and Hasan, 2013).

Focusing on improving efficiencies in the farm-made and small-scale feed manufacturing sectors is likely to bring significant gains to on-farm feed efficiencies. These sectors are currently constrained by a number of factors including inadequate access to finance, technical innovations, feed formulation and processing knowledge, and training. The potential to develop public-private partnerships with farmer groups and associations to share resources and improve access to improved manufacturing capacity should be considered.

3.1.3 Feed transport, storage and handling

The majority of the case studies revealed that farmers were generally unaware of the importance of applying appropriate feed transport, handling and storage techniques. Imported commercial diets are particularly vulnerable to spoilage during shipping

because sea freight storage conditions are sometimes suboptimal and, depending on the route, delivery times can be significant. Likewise transporting feeds in open trucks, motorbikes and bicycles can also result in long transit times and, on poor roads, this can result in the pellets being damaged, and a concomitant increase in fines (Rana and Hasan, 2013). In the Philippines, the majority of tilapia farmers were found to be unfamiliar with feed storage issues, and tended only to learn about appropriate storage practices after experiencing feed storage problems (Romana-Eguia, Laron and Catacutan, 2013). Poor feed storage practices manifest as a range of malpractices, ranging from the surveyed tilapia farmers of Ghana that stored their feeds in the open or under tarpaulins at night, exposing them to moisture, pests and inclement weather (Awity, 2013), to Indian shrimp farmers that were storing their feeds in metal containers and exposing them to the sun and excessive heat (Ramaswamy, Mohan and Metian, 2013). Inappropriate feed storage conditions can result in nutrient loss, feed spoilage, lower yield and poor economic returns. Prolonged exposure to unfavorable storage conditions and exposure to light, heat, humidity, air and water, or microbial/pest infestation (bacteria, fungi, insects and rodents) negatively impacts feed quality (Tacon, Jory and Nunes, 2013). Feeds should be stored in cool ventilated areas that are not exposed to the elements and extremes of heat and humidity and are protected from pests; feeds should also be used on a first in: first out basis. Hecht (2007) reported that small-scale feed producers and fish farms usually have small facilities that do not allow the bulk purchase of raw materials when prices are low, adding to feed costs. Where necessary, better management guidelines focusing on feed storage and handling issues need to be developed and communicated to the farmers (FAO, 2010; Section 3.6).

3.1.4 Top dressing and feed additives

The addition of chemicals to feeds by the farmers, known as "top dressing", usually requires the finished feeds to be sprayed with materials that are absorbed into the feeds. This process is generally used to add therapeutants, probiotics or nutrients that the farmers believe to be deficient or absent in the feeds or that act as feed attractants to stimulate consumption. This practice has been reported across a number of sectors. For example, 75 percent of the Indian shrimp farmers reported using probiotics and feed additives, adding US$39/tonne to the feed cost (Ramaswamy, Mohan and Metian, 2013).

The major concerns related to the practice of top dressing include the source and quality of the chemicals that are applied and their cost and efficacy. Of particular concern is the control and use of therapeutants such as antibiotics and hormones. In addition to the possible legality of using these chemicals, if applied incorrectly their use may result in animals being dosed at sub-optimal levels impacting their efficacy, possibly promoting disease resistance, and negatively impacting the environment. In addition, if farmers purchase their medicines from unscrupulous traders, they may end up using inappropriate chemicals that are either illegal, adulterated or of poor quality with low levels of active compounds, or not fit for purpose (Robb and Crampton, 2013). Additional concerns include worker exposure to active chemicals, and consumer safety because of farmers not applying the correct withdrawal periods. While many countries have developed regulations to control the use of veterinarian medicines in aquafeeds, compliance is often lacking, and regulatory authorities are often ill equipped to monitor their distribution and use.

A further issue is the cost and the efficacy of the chemicals that are being applied. It is evident that many farmers are using additives in the belief that they are improving their production parameters but few of these products have been empirically tested in terms of their efficacy and their cost effectiveness. It remains unclear whether the farmers are simply adding to their production costs, or whether there are real and demonstrable advantages from their use.

Depending upon the sector and the country, addressing these issues will probably require a number of interventions including farmer education; the development of better management practices to inform farmers when and how to top dress their feed and of the legal status of the therapeutants and chemicals; improvements in regulatory controls and compliance; and research to establish the efficacy and cost effectiveness of the various additives chemicals that are in use.

3.2 Feed monitoring and on-farm feed management

3.2.1 Optimizing feed management strategies

The profitability of a commercial farming operation is of paramount importance to the farmer. Adopting appropriate feed management strategies is instrumental in ensuring that feed use is optimized and that the highest economic returns are available to the farmer (FAO, 2010). While maximum growth rates will be attained by feeding to satiation, over- or under-feeding will result in feed inefficiencies (Kaushik, 2000) and, in the case of over-feeding, increased levels of farm effluents. Underfeeding manifests itself in lowered growth rates and increases in size heterogeneity in the population as hierarchies develop (Jobling, 1983; Houlihan, Boujard and Jobling, 2001). Optimization of feeding strategies requires farmers to calculate appropriate ration sizes and feeding rates, feeding frequencies, and feeding times that take into consideration the endogenous feeding rhythms of the farmed species. The case studies reported in this document revealed that farmers that are using commercially manufactured feeds are often but not always supplied with feeding tables, and are provided with technical support to assist them in determining ration sizes and feeding schedules. In many respects it is in the interest of the feed manufacturing company to ensure that their feeds are used appropriately - it promotes good production outcomes for the farmers and enables them to develop long term commercial relationships. Farmers that perceive that they are getting poor growth responses from a feed will quickly change their supplier. Those farmers that are using farm-made feeds and purchase feed ingredients from suppliers are less likely to have access to the information that they need to determine how they should design their feeding regimes. In the absence of this information, farmers will find it difficult to determine appropriate feed rations, and in many respects, they are more likely to adopt inappropriate feeding strategies.

Nevertheless, even when feed tables are available, the surveys carried out in the case studies revealed that many farmers do not use them, or apply them inappropriately. In China, Liu *et al.* (2013) found that the majority of tilapia farmers did not feed their fish according to the prescribed rates suggested by their feed tables, and failed to take into consideration ambient temperature, body mass and pond biomass when determining feed rations. Perhaps not surprisingly, the one survey farmer that maintained feed records and adjusted feed rates according to the prescribed feed tables reported the best feed conversion ratios, attesting to the importance attached to optimizing feed management practices. Likewise, the Indian major carp farmers surveyed in Bangladesh did not generally monitor their feed use, or use FCR to determine feed efficiencies (Sarder, 2013), probably resulting in farmers feeding sub-optimally. While the use of farm records to monitor feed use and efficiency was variable across the case studies, it was evident that many farmers were not keeping adequate production records; relatively simple farm data such as stocking rates, mortality, feed use and water quality were not always being recorded. In the absence of this data it is difficult for farmers to assess and monitor the efficacy of their production systems and to determine whether changes to their management strategies have demonstrable improvements on production efficiencies. There is a clear need to train farmers in feed management practices, promote the use of feed tables and ensure that farmers maintain adequate feed and production records.

An aspect of feed management that is often overlooked is the human dimension. Tacon, Jory and Nunes (2013) noted that on the larger shrimp farms, feeding is often the remit of those workers who often lack technical understanding of the importance of optimizing feed management, are poorly paid, and are seldom incentivized to improve feed management and efficiency. Unsurprisingly, feed management under these conditions is often far from optimal. Indeed on some commercial tilapia farms in Malaysia, it was reported that hired farm workers tended to overfeed the fish in the mistaken belief that feeding more produced higher growth rates (Ng *et al.*, 2013). Tacon, Jory and Nunes (2013) further drew attention to the fact that feed management regimes in shrimp culture are often designed to suit the farmer or farm worker, and have little regard to the behavioral preferences of the farmed species. As shrimp feeding activity is highest during the night, feed regimes should focus on delivering feed at night - not during the daylight hours when it is convenient for those presenting the feed.

In many instances innovative farmers have reported developing their own feeding strategies to optimize feed use. For example, in Andhra Pradesh, India, the majority of Indian major carp farmers reported that they spread their farm-made feeds at fixed points in their ponds (Ramakrishna, Shipton and Hasan, 2013). Simply placing their mash feeds in this manner resulted in much of it being dispersed in the water column and being wasted. More innovative farmers employed a "bag feeding" method in which the feed mixtures were placed in bags that were located throughout the pond. This method, also reported by the Indian major carp farmers of Bangladesh, promotes demand feeding and results in higher growth rates, improved feed ingestion rates, and higher retention rates because less feed is lost to the water column (Sarder, 2013). Other innovative feed management practices reported by the carp farmers in Andhra Pradesh included the development of restrictive feeding regimes, in which the fish are left unfed for one day in every ten days – a practice that is designed to reduce feed costs and stimulate compensatory growth. A similar restrictive feeding practice was reported by some of the striped catfish farmers in Viet Nam (Duong, Le and Nguyen, 2010). While the potential for restrictive feeding regimes has been demonstrated experimentally in the North African catfish (*Clarias gariepinus*) in Africa (Hecht, 2013), it has yet to be adopted as a farming strategy (Ali, 2001; Ali and Jauncey, 2004); carp farmers in Andhra Pradesh have also developed "break feeding schedules" in which feed rations are split into two rations, delayed by 20 minutes (Ramakrishna, Shipton and Hasan, 2013). The practice allows the dominant fish to be fed to satiation during the first round, and the smaller fish to reach satiation during the second feed round. As the practice improves satiation levels across the entire culture population, it promotes minimal size variations at harvest. Additional strategies include: 1) the use of feeding enclosures to make it easier to apply floating feeds and prevent feed wastage, and 2) cooking selected mash feed ingredients that are high in starch (e.g. broken rice) to promote gelatinization, increase digestibility and nutrient availability (Nandeesha, Sentilkumar and Antony Jesu Prabhu, 2013). Evidently, the role that the innovative farmers play in improving on-farm feed management practices is an important one, and mechanisms need to be developed to promote and communicate these innovations to other farmers (Section 3.6).

3.2.2 The role of natural productivity and the implications for feed management

Promoting natural productivity to provide a feed source for low trophic feeders such as tilapia, carp and shrimp is a common practice that was widely reported in the case studies. The use of inorganic and organic fertilizers in extensive and semi-intensive production systems is a well-established practice; however, considerable differences exist in the type of fertilizers used and in their availability, cost, and application rates. While many farmers were able to maintain natural productivity adequately in their culture systems, others, most notably in Africa, were reported to fertilize at sub-

optimal levels resulting in lower levels of production (Hecht, 2007; Pouomogne, 2007; Abban, 2005). In such cases, training farmers to use simple indicators to measure the levels of natural productivity in their ponds and providing information to enable them to manage their phytoplankton, zooplankton, benthos and periphyton production through appropriate fertilizer use would improve their production efficiencies.

The need to establish the qualitative and quantitative relationships between natural productivity and the impact that the use of supplemental and farm-made feeds have on nutrient cycling and retention in the culture may be also be pertinent to improving production efficiencies in extensive and semi-intensive production systems. The comparative role of feeds versus natural productivity on the nutrition of the farmed animals is poorly understood. Feeds often play a dual role by providing nutrition to the animals being farmed and as a nutrient source to stimulate natural productivity. Developing a better understanding of these dynamics is central to improving nutrient retention in the farmed species and the culture system, improving feed formulation, reducing feed costs and improving the efficacy of feed management systems.

3.2.3 The use and efficacy of feeding devices

Kaushik (2013) presented a review of the feeding devices that have been developed for salmonids and are increasingly being applied to other species groups. The case studies demonstrated that small-scale farmers generally rely on hand feeding; only selected sectors have embraced automated feeding devices. For example, while the majority of tilapia farmers in China use automated feeding systems (Liu *et al.*, 2013), they were only reported on selected farms in Thailand and Malaysia and were absent from the Philippines, Ghana and much of the rest of sub-Saharan Africa, where the majority of small-scale farmers still rely on hand feeding. A similar situation was found with the Indian major carp producers; with the exception of some feeding strategies such as the "bag feeding" technique, which is effectively a simple form of demand feeding, farmers also tended to rely on hand feeding. Shrimp production is also primarily based on hand feeding and the use of feeding trays to monitor consumption.

While hand feeding has the advantage of enabling farmers to monitor feeding behavior and adjust rations accordingly, automated feeders can be cost effective, reduce labor requirements, and allow large volumes of feed to be fed efficiently. In the case of demand feeders, they have the advantage over hand feeding in that they take into consideration the behavioral rhythms of the farmed species, return of appetite, and the nutritional quality of the diet. The choice and complexity of the automated systems required is dependent on the farmed species, the size of the fish and the design of the culture system (Kaushik, 2013). For example, simple belt feeders can be used in hatcheries to supply low quantities of feed to fry which often require feed on a near continuous basis. In grow-out systems, more complex systems such as static demand feeders and movable mechanical systems based on compressed air can be applied. In those species where feeding hierarchies develop, computer controlled automated feeders using video or infrared sensors to monitor consumption can be particularly effective in ensuring that all the fish are fed to satiation. For example, while dominant Atlantic salmon feed voraciously at the surface and reach satiation rapidly, the subdominant fish eat lower in the water column and take longer to reach satiation. Linking feed monitoring systems to automated feeders ensures that both the dominant and subdominant fish are fed to satiation (Robb and Crampton, 2013).

While many of the more complex systems require electricity and a relatively high level of technical expertise, they would also be costly to install and operate making them unsuitable for small-scale rural producers. However, there are alternatives, such as simple mechanical demand feeders that could be used by small-scale farmers to improve their on-farm feed management. The use and efficacy of these systems needs to be established and, where appropriate, their adoption encouraged.

3.3 Feed management and the environment

Feed quality and feed management practices play a significant role in the environmental impacts that add to a farming operation. Inappropriate feeding strategies, and in particular those that result in overfeeding are a major cause of excess nutrients entering the environment. Overfeeding causes reduced feed efficiencies (Talbot, Corneillie and Korsøen, 1999), increased feed wastage (Thorpe and Cho, 1995) and in many cases increased environmental degradation (Cho and Bureau, 1998). Depending upon the efficiency of the feed formulation and the feed management practices, approximately 15–25 percent of the nitrogen in the feed is retained by the culture animals with the remainder entering the surrounding environment in either soluble or particulate form (Boyd and Clay, 2002). Likewise over 75 percent of the total carbon and phosphorus that is provided in the feed is excreted via the gills or released as particulate matter (Holby and Hall, 1991; Hall *et al.,* 1992). The negative environmental impacts associated with nutrient and organic enrichment include increases in the biochemical oxygen demand in the water bodies and sediments (anoxic sediments), changes to community structures and eutrophication (Barg and Phillips, 1997).

Optimizing feed formulation, quality and feed management practices can play a key role in limiting nutrient inputs into the aquatic environment, and minimizing the environmental impacts of farming operations. The high feed conversion ratios that are associated with poor quality feeds and/or poor feed management practices manifest as increased nutrient loadings, and an increased potential to impact the receiving environment negatively. The case studies reported large variations in FCR that were attributed to both feed type and feed management. For example, in semi-intensive striped catfish pond culture in Viet Nam, Nguyen (2013) reported FCR of 1.6:1 and 2.9:1 when commercially manufactured and farm-made feeds were used respectively. While the nutritional composition and feed management practices would have differed between the two feed types, the result suggests that commercially manufactured pellets were more efficient than the farm-made feeds, and the commercially manufactured feeds would have probably resulted in lower effluent loadings. Likewise in India, in semi-intensive pond culture of the Indian major carps, Ramakrishna, Shipton and Hasan (2013) reported FCR of 1.8–3.4:1 and 2.3–4.1:1 using commercially manufactured pellets and farm-made feeds respectively. Despite differences in feed formulations and feed management practices, it is reasonable to suggest that the commercial feeds would generally have produced lower emissions.

A common theme across the case studies was the quality, availability (temporal and spatial) and high costs associated with many of the feed ingredients used in farm-made feeds. Often the quality of farm-made feeds depends on ingredient availability, cost and farmers' perceptions of the correct quantities to use. As nutritional imbalances lead to reduced production performances and increased effluent, there is often a need to improve the on-farm feed formulations that the farmers apply. The use of cost-effective formulations that are water stable, palatable, have a nutrient composition that targets the specific developmental stage of the fish and, where appropriate, take into consideration the endogenous availability of natural food organisms (e.g. shrimp culture, semi-intensive Indian major carps and tilapia culture) will improve production parameters (growth and FCR), improve the economic efficiency of the operations, and have a positive effect on the environmental impact of the farming operation.

Similarly, poor feed handling, storage and spoilage prior to ingestion will result in poor feed efficiencies and increased environmental degradation. Sub-optimal feed management strategies, and the need to develop and promote better feed management practices were cited as priority interventions in many of the case studies presented. Improving feed management practices would improve production economics and reduce the environmental impacts associated with the farming operations.

3.4 The economics of feed management

The implications of feed type, formulation and feed management practices on the economics of the farming operation are important issues that farmers need to take into consideration when planning their farming activities. While these economic interrelationships are often difficult for farmers to assess, they can have a profound effect on the profitability of the farming operation (FAO, 2010; Shipton and Hecht, 2013).

These relationships are most evident in highly competitive sectors where feed costs represent a high percentage of the production cost, the farm-gate prices are low, and profitability is marginal. Nguyen (2013) demonstrated that when striped catfish farmers in Viet Nam used commercially manufactured feeds, their feed costs accounted for 82.9 percent of total production costs. When a mixture of farm-made feeds and commercially manufactured feeds were used, this percentage was reduced to 79.0 percent, and further reduced to 77.4 percent when farm-made feeds were used as the sole food source. While using farm-made feeds appears to be the cheaper option, and switching to them reduces investment costs, they are less efficient in terms of growth and FCR; thus, in terms of real production costs (cost/kg fish produced), they are more expensive to use. This study demonstrated that the total cost of production using farm-made feeds was US$0.88/kg fish, whereas it was US$0.79/kg fish for farmers using commercially manufactured feeds or a combination of commercially manufactured and farm-made feeds. Feeding commercially manufactured feeds or in combination with farm-made feeds thus increased profits by US$0.09/kg compared to the exclusive use of farm-made feeds. This represents a significant cost saving – which is of critical importance when farm gate prices are so low. Nguyen (2013) noted that the high cost of commercially manufactured pellets had forced some resource poor farmers to revert to farm-made feeds, or to use them when farm-gate prices were low. While there is some scope for substitution with farm-made feeds, the economic analysis suggests that while reverting to farm-made feeds may reduce feed costs, farmers need to recognize that there will be a concomitant reduction in profits. Evidently, resource poor farmers resort to the cheaper farm-made feeds when they are unable to afford the more expensive but ultimately more productive and profitable commercially manufactured feeds. In some sectors, credit schemes between feed manufacturers, dealers and the farmers have been developed. These types of micro-lending models need to be encouraged and novel ways to fund feed purchases sought, possibly through the development of farmer groups and associations, bulk buying schemes, the involvement of banks and micro-lending institutions, and the development of public-private partnerships.

The relationship between feed management practices and the economic efficiency of the farming operation is an important consideration for farmers, and provides them with the rationale for choosing one feed management practice over another. Using a bio-economic model of an intensive re-circulation system for culturing the Japanese meagre (*Argylosomus japonicus*), Shipton and Hecht (2013) demonstrated how deteriorating feed management practices, manifesting as a reduction in FCR, impacted the economic viability of the farming operation. As a simple example, on a 600 tonne per annum farm it was established that a increase in FCR from 1.0:1 to 1.6:1 increased feed costs as a percentage of total production costs from 36.2 percent to 46.1 percent, and increased annual farm operational costs by 22.9 percent. The analysis highlighted the economic importance of optimizing those feed management practices that impact FCR – and, ultimately, profitability. Amongst others, these include optimizing feeding frequency, ration and rearing temperature. In tilapia culture in Thailand, Bhujel (2013) also considered the use of feed and their effect on culture periods and production costs; he concluded that, as well as the factors outlined above, additional factors such as land, water and pond excavation costs also need to be considered. In those cases in which the cost of land rental or purchase was expensive then higher density fed-lot type systems become a more economically viable option.

Farmers need to consider a large number of parameters that affect on-farm feed utilization, and ultimately profitability. Principal amongst these are: systems design (e.g. extensive versus intensive farming systems); operational parameters (e.g. temperature, water quality); feed type and formulation; and feed management practices (e.g. feeding schedules). In general, farmers do not have access to this information, and there is a need to develop economic tools to assist farmers to understand the implications of their feed choices and management strategies.

3.5 Aquafeed policy, regulations and governance

In many case studies, poor regulatory control and a lack of standards throughout the aquafeed value chain were cited as constraints to feed supply, quality and use. Major issues reported were: the use of poor quality or adulterated ingredients; a failure to use appropriate product labeling; and the misrepresentation of products and/or a lack of standard feed specifications, resulting in inappropriate formulations being sold to farmers. As there has been limited assessment of the quality of the feeds that are available (Kader, Hossain and Hasan, 2005), farmers are usually reliant on feed ingredient suppliers and manufacturers to provide quality products. This issue is particularly pertinent to resource-poor, small-scale farmers who, on purchasing poor quality or sub-standard feeds and feed ingredients, have little practical recourse to the supplier or manufacturer. In the light of these issues, the role of aquafeed regulation and governance in ensuring the quality of feed and feed ingredients and optimizing production becomes pertinent (FAO, 2010).

A review of the governance mechanisms and the role that legal, policy and regulatory instruments play in ensuring feed quality revealed that there were significant regional variations in the regulatory instruments that are used to control the sector. It was evident that the quality of commercially manufactured feeds is generally high in developed countries where the sector is characterized by large-scale industrial production and fewer feed manufacturers (a more consolidated feed manufacturing sector). In these countries, the regulations relating to feed manufacturing, use and management are designed to ensure feed quality and to limit the environmental impact of their use (Shipton and Hecht, 2013). In contrast, in less developed regions such as Asia, many production sectors are dominated by small-scale farmers using farm-made feeds or commercially manufactured feeds procured from a pool of small-scale feed manufacturers. Arguably, in these areas, regulations are more focused on regulating feed quality and ensuring that farmers have access to good quality feeds, with less emphasis on the environmental impact of their use. In practice, few countries in Asia have the regulatory measures in place to check ingredient and feed quality on a regular basis (De Silva and Hasan, 2007); regulatory measures are certainly less available in other regions such as sub-Saharan Africa (Hecht, 2007; El-Sayed, 2013).

Nevertheless, there are positive signs of appropriate feed regulatory frameworks starting to be developed and adopted in less developed producer countries. For example, Bangladesh and Viet Nam have recently introduced new regulatory frameworks for the manufacture and trade of aquafeeds (Hasan, 2012b; Nguyen, 2013). In Viet Nam, these new dispensations require feed mills to be registered, feed standards to be applied, and regular product monitoring to be carried out (Nguyen, 2013). In contrast, in India, there are currently no feed regulations in place for freshwater aquaculture. However, in saline and brackishwater systems, the Coastal Aquaculture Authority (CAA) has limited powers to review feed mill registration, and the aquafeed manufacturing industry is currently subject to voluntary codes of practice. The CAA is planning to introduce a legally binding framework in the near future (Ramaswamy, Mohan and Metian, 2013). In sub-Saharan Africa, no regulatory standards exist in terms of feed composition, feed performance, feed use, effluent treatment or levels, and no codes of conduct or better management practices have been developed or adopted (El-Sayed, 2013).

Traditionally, government agencies provide the legal, policy and regulatory frameworks under which aquaculture and aquafeed use is controlled. In recent years, the emergence of certification bodies such as the Aquaculture Stewardship Council (ASC), the Aquaculture Certification Council (ACC) and the Global Aquaculture Alliance (GAA) has seen a new approach to governance. In many respects these "non-state, market-driven" systems (Vandergeest, 2007) now compete with traditional governmental regulators, in what some authors have termed "the privatization of governance" (Gereffi, Garcia-Johnson and Sasser, 2001). Increasingly, market access, and in particular export orientated markets to the developed world, are being driven by certification programs and compliance standards. Feed and feed use are major components of these standards, and from a market access perspective, it is becoming increasingly important that governments put in place regulatory measures to control and monitor feeds and feed ingredient quality to ensure compliance.

The development of regulatory frameworks to control the quality of feeds available to farmers needs to be accompanied by institutional capacity to enforce the regulations and ensure compliance. Monitoring feed production and quality is a complex and expensive undertaking, and the case studies suggest that many of the countries that have developed appropriate regulatory frameworks lack the institutional capacity to enforce them. The role that non-government actors such as the national feed industry associations can play in facilitating the sustainable development of the aquafeed manufacturing sector also needs to considered (Tacon and Hasan, 2007).

3.6 Training and developing information networks to improve feed management

Training and the dissemination of information to farmers and particularly small-scale farmers that have limited exposure to the latest technological and management developments is an issue that needs to be addressed (FAO, 2010). Most farmers using farm-made feeds operate at the household level and have relatively limited education; thus the transfer of complex technical messages is problematic and requires continuous attention (Hasan *et al.,* 2007). Weak extension and information dissemination networks result in low adoption rates of new feed production technologies and better management practices.

Farmer clusters and associations have proved an effective platform for information dissemination and promoting farmer to farmer training. Farmer clustering is becoming increasingly prevalent across Asia, and is more recently being adopted in some African countries. For example in Kenya, tilapia farmers are now being encouraged to form farmer associations (AquaFish CRSP, 2009), and across Asia, small-scale shrimp farmers in India, Indonesia, Bangladesh and Viet Nam are increasingly becoming organized into groups/clusters. In addition, the identification and training of key innovative farmers to train other farmers, and farmer field schools have proved successful and need to be promoted further. While training needs are sector specific and are described in more detail in the case studies, it is clear that they generally focus on the need to improve feed formulations; formulate species- and life-stage specific diets; and improve the understanding of ingredient quality, nutrient composition and selection, manufacturing processes, storage, and on-farm feed management practices.

Access to up-to-date market information for small-scale feed manufacturers and farmers producing farm-made feeds is an issue that needs to be addressed. While large-scale manufacturing operations generally have access to, and are aware of the cost, availability and nutrient composition of the ingredients that are on the market, this is not always the case for the farmers and small-scale feed manufacturers. Contemporary market information including sources, suppliers, quality and cost is a prerequisite to the development of cost-effective farm-made feeds. Furthermore, the use of appropriate local and seasonally available feed ingredients that can be incorporated into farm-made

feeds also needs to be encouraged. Farmers and small-scale feed manufacturers need to be made aware of the availability of these ingredient sources, and how they can best be incorporated into their formulations. Currently, information networks are either inefficient or lacking, and there is a need to promote programs that use local media to supply farmers with up-to-date feed ingredient availability, quality, price and supplier details. In addition, farmers require access to information pertaining to species-specific feed formulations and ingredient inclusion rates. Area-specific databases containing feed ingredient supply and cost information that are easily accessed by farmers and small-scale feed manufacturers could also be considered.

4. RECOMMENDATIONS

The following recommendations are based on the issues and constraints highlighted in the case studies and reviews in this technical paper. Improvements to the nutritional quality, methods of preparation and on-farm management of aquafeeds will bring about productivity gains and cost savings to farmers; thus the majority of these recommendations pertain to the quality of the aquafeeds and on-farm feed management practices. Recommendations relating to the broader issues of training needs, information dissemination and regulatory frameworks are also provided.

1. Initiate research and development programs that focus on improving the nutritional quality of farm-made aquafeeds. Provide farmers and small-scale feed manufacturers with species and life-stage specific feed formulations that take into consideration existing knowledge, ingredient quality and seasonal availability, processing technologies, performance and price.
2. Improve on-farm and small-scale feed manufacturing technologies, feed handling and storage techniques. Technical and financial support to this manufacturing sector will improve feed quality, reduce feed costs and increase farm productivity. The potential to develop public-private partnerships with farmer groups and associations to share resources and facilitate access to improved manufacturing capacity should be considered.
3. Determine the extent and efficacy of "top dressing" procedures. Establish the dose, efficacy and cost-effectiveness of the chemicals and materials used. Characterize the environmental impacts associated with their use. Where appropriate, develop policy, regulations and guidelines to control and monitor their use.
4. Teach farmers about the importance of feed management practices in optimizing production parameters. Establish the use and efficacy of automated feeding systems and promote the use of feeding tables and maintaining feed and production records. Provide farmers with simple tools to monitor farm production indices and training on how to take corrective actions.
5. Establish the roles that natural productivity, feed and fertilizer use have on nutrient recycling and retention in extensive and semi-intensive production systems. Develop appropriate feed formulations that take into consideration the role of natural productivity in providing nutrition to the culture animals.
6. Develop monitoring protocols to assist farmers to optimize natural productivity in their extensive and semi-intensive production systems.
7. Identify and optimize new feed management practices and develop better management practices (BMPs) that can be communicated to farmers through farmer groups/associations, extension networks and the media.
8. Develop and disseminate economic tools to assist farmers to understand the implications of their feed choices and optimize their feed management strategies.
9. Develop appropriate aquafeed policies, regulatory frameworks, and feed standards in those countries that do not already have them. Poor regulatory control and a lack of standards along the aquafeed value chain are constraints to feed and

feed ingredient quality. Farmers must be assured of the quality of the feeds and feed ingredients that they are purchasing. Enhance and develop capacity at those institutions responsible for monitoring and compliance.

10. Provide up-to-date market information for small-scale feed manufacturers and farmers producing farm-made feeds. Promote programs that use local media to provide farmers with up-to-date feed ingredient availability, quality, price and supplier information, feed formulation and ingredient inclusion rates.

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On-farm feeding and feed management practices for sustainable aquaculture production: an analysis of case studies from selected Asian and African countries

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ABSTRACT

Aquaculture production reached some 79 million tonnes in 2010. During the period from 1998–2010, production from feed-dependent aquaculture increased more than twofold from 20 to 45 million tonnes, largely through intensification. The use of exotics with established technologies such as tilapias, carps, shrimps and salmonids provided firm market opportunities for increasing production and driving production efficiency.

This review considers changes in feed and feed management practices in selected countries (Bangladesh, China, Egypt, Ghana, India, the Philippines, Thailand and Viet Nam) that contributed to this increase. Four major farmed species groups of freshwater finfish and shellfish: tilapias, catfishes and Indian major carps, and shrimps and prawns are considered. These groups showed a phenomenal growth in production, increasing from 1.6 million tonnes in 1988 to 16 million tonnes in 2010, with a single species within each species group dominating production. The contributions of these species to production are presented. Ponds (1–5 ha) continued to be the predominant production system but the use of cages in countries such as Egypt, the Philippines and Ghana is on the increase. The types and changes in farming practices are discussed. The key trigger for change in culture practices was market opportunities, combined with the need for increased production and productivity to reduce costs.

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Two fundamental changes in farming practices that contributed to this increase are evident and discussed: the increase in the use of formulated farm-made and commercial aquafeeds and the concomitant aeration of ponds/tanks. In India the introduction of stocking large fish, together with supplementary feeding, was a notable shift in farming practice. For tilapia, intensification through the introduction of stocking larger fish, aeration, increased feed inputs and a shift to culture in cages characterized the changes in farming practices in countries such as the Philippines, Egypt, and Ghana. The high international prices and availability of hatchery reared postlarvae encouraged many small to medium-sized farmers in Bangladesh and India to change culture practice to focus only on freshwater prawns and shrimps in larger ponds (0.2–0.4 ha) using supplementary feeds and aeration, pushing shrimp yields up to 3–5 tonnes/crop. Such developments and their associated challenges and approaches for improving production and production efficiencies and reducing feed costs for the selected countries are detailed in the review. Additionally, the implications of fish mortality on feed utilization efficiencies and cost are modelled using case study scenarios.

1. OVERVIEW OF GLOBAL PRODUCTION

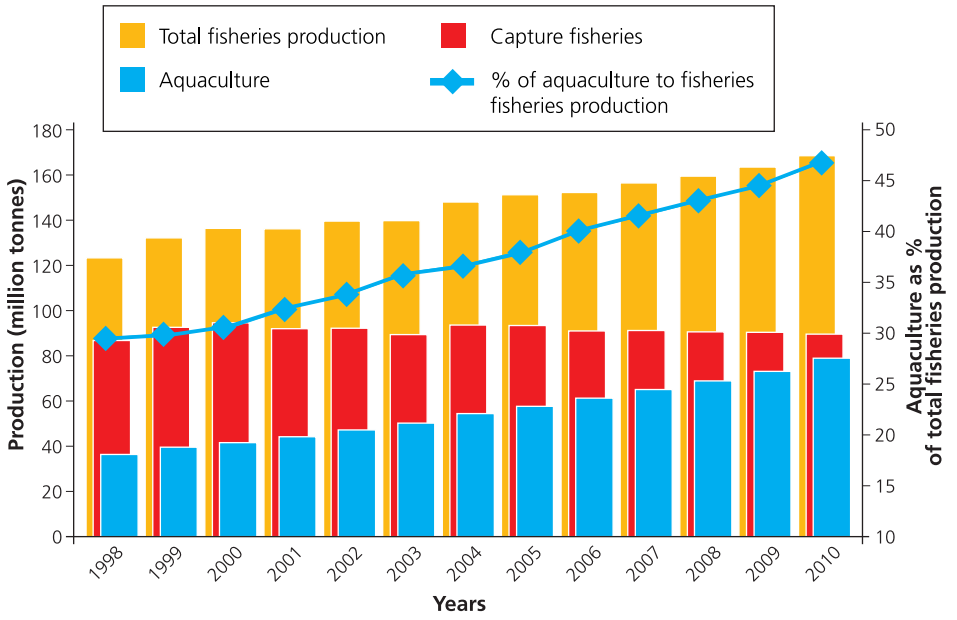
1.1 Global aquaculture production

It is now internationally accepted that the increased supply of fish products required to meet global demand cannot be sourced from wild fisheries, which are either stagnant or declining (FAO, 2012a). To meet their national and international demand, nations around the world have continuously developed and improved technologies and management, especially feed and feed management practices, to increase production volumes and efficiencies for a range of aquatic organisms in an environment of limiting natural resources.

Although there are large intercountry differences in sector growth, aquaculture has collectively achieved the highest average growth rate among the animal production sectors. In 2010, global aquaculture production reached 79 million tonnes, growing at an annual rate of 9.7 percent since 1998, while technological advances in equipment and feed and greater areas under culture have led to an increase in its proportional contribution to total fisheries (Figure 1). In 1988, aquaculture contributed only 15 percent of total global fisheries production; by 2010, however, this had risen almost threefold to 47 percent. This increased contribution, however, is largely an Asian phenomenon, as Asia accounted for 72 million tonnes or 91.5 percent of total world aquaculture production in 2010, while the Americas, Africa and Europe contributed only 3.3, 1.8 and 3.2 percent, respectively. Global production was valued at US$125 billion, with the share of the Asian region being US$102 billion, or 81 percent of total world aquaculture value. This increasing trend is projected to continue in future decades; consequently, the aquaculture sector is expected to play a significantly greater role in contributing to food security, poverty alleviation and economic improvement for the poor.

Over the past 15–20 years, more than 60 countries have engaged in farming over 200 species or species groups of aquatic animals and plants in a vast range of production systems, ranging from low-input extensive to high-input intensive aquafarms using ponds, caged enclosures and tanks. In broad terms, aquaculture systems used for the production of these aquatic animals and plants can be divided into feed-dependent systems or “fed aquaculture” (e.g. finfish and crustaceans) or non-fed aquaculture systems, where culture is predominately dependent on the natural environment for food and nutrients (e.g. aquatic plants and molluscs).

FIGURE 1
Global trends in contribution of aquaculture to fisheries production, 1988–2010



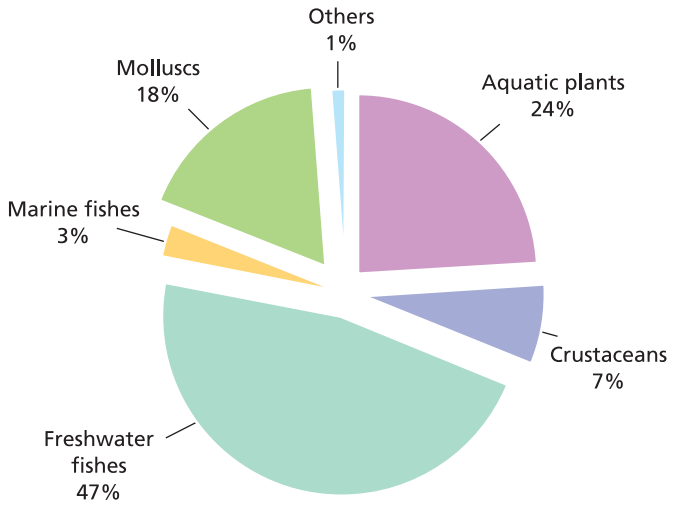
Source: Adapted from FAO (2012b).

1.2 Global and country profiles of species and species group utilization in aquaculture

Although more than 200 aquatic species or species groups are farmed, the majority of production stems from a few species and species groups that are cultured with minimum impact on the environment when compared with other food production sectors such as agriculture and livestock, while still maximizing benefits to society.

In 2010, freshwater fish accounted for 47 percent of global production, while the remaining 53 percent was of marine origin (Figure 2). Of this 53 percent, about 92 percent comprised aquatic plants and shellfish (except abalone), which are not dependent on feed and, as such, actually remove nutrients such as nitrogen and phosphorus originating from anthropogenic activities, especially agriculture and sewage disposal. Seaweeds and algae utilize these nutrients for growth, and shellfish filter the resultant algae as food. Similarly, freshwater and marine fish species that filter algae and zooplankton can also have the same positive impact. This removal of nutrients from the water can reduce the risk of coastal algal blooms and ameliorates the negative impacts of the agriculture sector, which is a significant contributor of these nutrients through the use of

FIGURE 2
Global output of aquaculture by species group, 2010



Source: Adapted from FAO (2012b).

fertilizers. Indeed, in 2007, more than 200 million tonnes of fertilizers (nitrogen-potassium-phosphorus [NPK]) were used globally in agriculture; much of this eventually entering the aquatic environment, both through runoff and via groundwater.

1.3 Range of species and species groups used globally in aquaculture

In 2010, only about a dozen species and species groups accounted for almost all global finfish production, with a few species dominating each region (Table 1). In Asia, carps (Chinese, Indian major and common), tilapias, catfishes, milkfish, shellfishes including crustaceans and seaweed predominate in regional production. In the Americas, salmon, trout and catfish predominate, accounting for 43 percent of total regional production. In Chile, salmonids, destined for export markets in the United States of America, Japan and Europe, dominate aquaculture production, while in the United States of America catfish are predominately produced for the domestic market. In Europe, almost half (46 percent) of the total regional production originates from just two species (salmon and trout) and, in both cases, most is exported, but largely within the European region. Species diversity within Africa is also narrow, with more than 77 percent of regional production originating from three species – Nile tilapia (*Oreochromis niloticus*), North African catfish (*Clarias gariepinus*) and flathead grey mullet (*Mugil cephalus*) – all for domestic consumption, with Egypt being the focus of production. Similarly, in Oceania, two species (salmon and mussels) account for almost 80 percent of the production of the region, with mussels being mainly exported. About half of the salmon farmed in Australia and New Zealand is consumed domestically.

A global snapshot of aquaculture production in 2010 by region and key aquaculture countries is presented in Table 1. This table also provides an assessment of scale, measure of biodiversity utilized in aquaculture and key purposes of production. In addition, the production by country is ranked within each region, and the countries included represent 80–97 percent of the total aquaculture output of their region and 99.8 percent of world output. Overall, freshwater fish are by far the most widely farmed group. An understanding of the fate of national aquatic output is valuable, as it may shed some light on macro-government policy on food security and economic development, especially as pertains to feed inputs.

The main destinations of national aquatic products are colour-coded in blue and purple font in Table 1. It is noteworthy that the vast majority of species and species groups of farmed aquatic products, that are freshwater fish, are destined mainly for domestic consumption. According to (FAO, 2012b), about 994 000 tonnes of freshwater fish (aquaculture and capture fisheries including river eels) entered the export market globally in 2009. This estimation includes products in all forms (fillets, fresh frozen, etc.) and therefore whole body weight equivalent is likely to be double that level. Nevertheless, this quantity is still a small proportion of total freshwater production. In contrast, 28.4 million tonnes of marine finfish and shellfish (aquaculture and capture) were exported globally during the same period, but the proportion of farmed marine finfish and shellfish contributing to total exports is unknown. Known species of shrimps that are mainly farmed accounted for 396 000 tonnes of exports in 2009 (FAO, 2012b), but given the final product forms, the whole body weight equivalents will be higher. About 3.2 million tonnes of shrimps and freshwater prawns were farmed globally (FAO, 2012b), although Table 1 shows global production as 2.92 million tonnes because it includes only major aquaculture producing countries in the world. With rising living standards in many Asian countries, a greater share of these products will enter the domestic and regional markets.

TABLE 1

Aquaculture production (thousand tonnes) hotspots by species and species groups ranked by country within regions in 2010.

[Product destination: numbers in blue font - largely domestic; purple font - largely exports; yellow cells denote use of exotic species]

		Finfish																Shellfish						
		Salmon	Trout	Chinese carp	Indian carps	Common carp	Tilapias	Catfish	Milkfish	Grey mullet	Seabream	Seabass	Freshwater fish nei	Mitten crab	Freshwater prawns	*P. monodon*	*P. vannamei*	Clam	Oysters	Mussel & abalone	Seaweed	Country total (thousand tonnes)[1]	% of country total[2] and regional total[3] (% of world share)[4]
Asia	China	1	16	10 381		2 538	1 332	792				106	626	593	15	56	1 223		3 643	759	7 884	47 830	63
	India			146	4 076								232			96	10		3	15	3 915	4 653	98
	Indonesia					283	459	374	422				143			125	207					6 278	94
	Philippines						259	3	349							48	5		23	21	1 801	2 546	99
	Viet Nam					110	76	1 150					188			333	137				35	2 707	75
	Thailand				3	3	179	135					5			5	561		28	167		1 286	84
	Bangladesh			223	600	46	25	140					29		6	43						1 309	85
	Myanmar			36	624	23	41	25								46						851	93
Total		**1**	**16**	**10 786**	**5 303**	**3 003**	**2 371**	**2 619**	**771**	**0**	**0**	**106**	**1 223**	**593**	**21**	**752**	**2 143**	**0**	**3 697**	**962**	**13 635**	**67 459**	**72 2033 (92.5)[4]**
% of regional total		0	0	15	7	4	3	4	1	0	0	0	2	1	0	1	3	0	5	1	19	93	
Americas	Chile	247	220																	225	12	713	99
	USA	20	15				10	217									1	30	138	2		495	87
	Brazil		5			95	155	5					10				69		2	14		480	74
	Ecuador						48										223					272	99
	Canada	114	7										1						11	24		161	98
Total		**380**	**247**	**0**	**0**	**95**	**213**	**218**	**0**	**0**	**0**	**0**	**11**	**0**	**0**	**0**	**293**	**30**	**151**	**265**	**12**	**2 122**	**2 589 (3.3)**
% of regional total		15	10	0	0	4	8	9	0	0	0	0	0	0	0	0	11	1	6	10	0	82	
Africa	Egypt					92	557	10		116	15	16										920	88
	Nigeria						12	133														201	72
	Uganda						32	63														95	99
	Madagascar					3										4					4	11	99
	South Africa		1																	2		5	58
Total		**0**	**1**	**0**	**0**	**95**	**601**	**206**	**0**	**116**	**15**	**16**	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**2**	**4**	**1 231**	**1 427 (1.8)**
% of regional total		0	0	0	0	7	42	14	0	8	1	1	0	0	0	0	0	0	0	0	0	86	
Europe	Norway	928	55																	2		1 008	98
	Spain		17								20	11							2	189		252	95
	France	1	33			4					1	3						2	96	77		225	97
	Italy		36								6	6								64		153	73
	UK	155	14																1	30		201	99
	Greece		3								54	31								23		113	98
	Russia	5	19	25		57																121	87
	Ireland	16	1																7	22		46	99
Total		**1 104**	**178**	**25**	**0**	**61**	**0**	**0**	**0**	**0**	**81**	**51**	**0**	**0**	**0**	**0**	**0**	**2**	**106**	**407**	**0**	**2 120**	**2 523 (3.2)**
% of regional total		44	7	1	0	2	0	0	0	0	3	2	0	0	0	0	0	0	4	16	0	44	
Oceania	NZ	13																	2	95		111	99
	Australia	32																	15	4		70	73
Total		**45**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**17**	**99**	**0**	**180**	**199 (0.3)**
% of regional total		22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	50	0	91	

Notes: USA = United States of America; UK = United Kingdom; Russia = Russian Federation; NZ = New Zealand.;
[1] Total aquaculture production including all other species/species groups; [2] Percentage of aquaculture production contributed by the species and species groups shown in this table; [3] Total aquaculture production of each region/continent; [4]Value in parentheses is the percentage of world share of aquaculture production contributed by the continent.

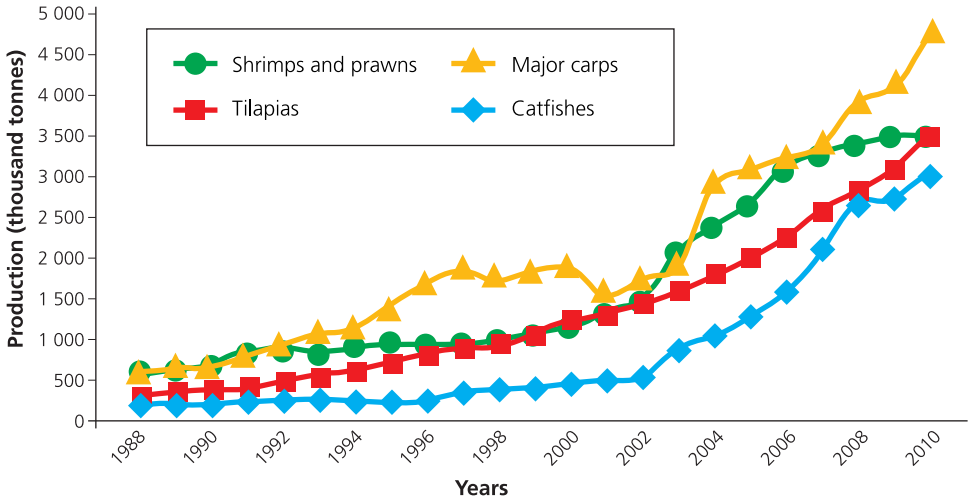
Source: FAO (2012b).

1.4 Synthesis of development trends for selected species/species-groups and countries

This review synthesizes the information derived from 11 case studies on feeding and feed management practices carried out in selected countries for eight species in four major farmed species groups of freshwater finfish and shellfish: shrimps and prawns, tilapias, catfishes and Indian major carps. These four farmed species groups totalled 14.8 million tonnes accounting for 24.7 percent of world finfish and shellfish production in 2010. For these species groups, the review focuses on country-specific case studies carried out for: Nile tilapia (*Oreochromis niloticus*) in China, Egypt, Ghana, the Philippines and Thailand; Indian major carps (rohu [*Labeo rohita*], catla [*Catla catla*] and mrigal [*Cirrhinus cirrhosus*]) in Bangladesh and India, giant river prawns (*Macrobrachium rosenbergii*) in Bangladesh; striped catfish (*Pangasianodon hypophthalmus*) and whiteleg shrimp (*Litopenaeus vannamei*) in Viet Nam; and black tiger shrimp (*Penaeus monodon*) in India.

The production of the above four species groups collectively increased from 1.6 million tonnes in 1988 to 14.8 million tonnes in 2010 (Figure 3), representing an annual average increase in production of 10.7 percent. Specific species, however, showed phenomenal growth. For example, annual production of whiteleg shrimp, increased from 77 000 tonnes in 1988 to 2 710 000 tonnes/year in 2010, an increase of more than 35 times (Figure 4). Globally, a single species within each species group dominated production. In 2010, the whiteleg shrimp accounted for 67 percent of all shrimp and prawn production, with 45 percent of world production reported from China (Table 2).

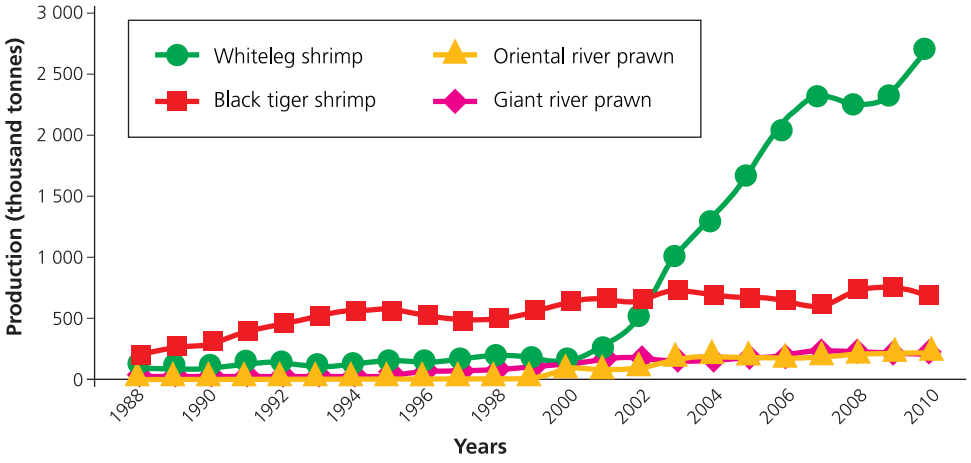
FIGURE 3
Production trends of selected species groups of finfish and shrimps and prawns, 1988–2010



Source: Adapted from FAO (2012b).

Similarly, in 2010, Nile tilapia, striped catfish and catla accounted for 73, 43 and 71 percent of production, respectively, in their species groups (Table 2). However, this dominance or ranking of preferred farmed species within species groups shows temporal variation both globally and nationally. In 1994, black tiger shrimp dominated production at 62 percent (559 000 tonnes), while whiteleg shrimp contributed only 13 percent (121 000 tonnes) of global shrimp and prawn production; however, by 2010 the trend had reversed, with black tiger shrimp production slipping to just 19 percent (685 000 tonnes) and whiteleg shrimp surging to 67 percent (more than 2 710 000 tonnes) of global shrimp and prawn production (Figure 4, Table 2).

FIGURE 4
Temporal changes in contribution of major species to global shrimp and prawn production, 1988–2010

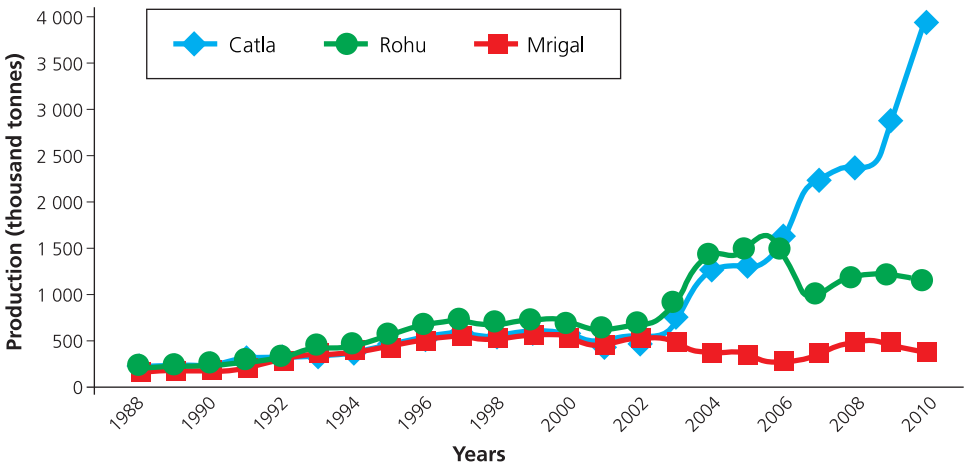


Source: Adapted from FAO (2012b).

For tilapias, there is a strong preference for farming *O. niloticus* over *O. mossambicus*. Since 1988, the contribution of *O. niloticus* to farmed tilapias has increased by more than 1.6 times, increasing from 45 percent in 1988 to 73 percent in 2010, with China and Egypt reporting 39 percent and 22 percent of world production, respectively (Table 2).

The United States of America was the main catfish (channel catfish) producer in the 1980s and 1990s, but it has been surpassed in this millennium by the phenomenal growth in striped catfish (tra or pangas) production in Viet Nam. By 2010, striped catfish production reached 1.14 million tonnes in Viet Nam, representing 37 percent of all global catfish production (Table 2), 87 percent of which was produced in Viet Nam. Channel catfish, which accounted for 80 percent of all catfish production in 1988, plummeted to just 15 percent by 2010 (Table 2) and about half (217 303 tonnes) of this was produced in China. Although China does not report any striped catfish production, it monopolizes the production of Amur and yellow catfish (Table 2).

FIGURE 5
Global production of Indian major carps



Source: Adapted from FAO (2012b).

TABLE 2

National and global aquaculture production of the selected species and species group in selected countries in 2010

Species group	Global	National production								
		China	Viet Nam	India	Bangladesh	Thailand	Philippines	Ghana	Egypt	Others
	Thousand tonnes (% of group)	Thousand tonnes [numbers in parentheses indicate % of global species production								
Shrimps & prawns										
Whiteleg shrimp	2 721 (67)	1 223 (45)	137 (5)			561 (21)				785 (29)
Black tiger shrimp	783 (19)	57 (7)	333 (43)	97 (12)	43 (6)	5 (1)	48 (6)			199 (25)
Giant river prawns	215 (5)	125 (58)	8 (4)	14 (6)	31 (14)	26 (12)				12 (6)
Others	316 (8)									
TOTAL	**4 034**									
Tilapias										
Nile tilapia	2 538 (73)	999 (39)				179 (7)	168 (7)	9 (0.4)	557 (22)	625 (24.6)
Others	959 (27)									
TOTAL	**3 497**									
Catfishes										
Pangas catfishes nei	1 307 (43)		1 140 (87)							167 (13)
Channel catfish	445 (15)	217 (49)								228 (51)
Amur catfish	380 (12)	374 (99)								6 (1)
Catfish, hybrid	117 (4)					117 (100)				0
North African catfish	191 (6)							0.570 (0.3)		190 (99.7)
Chinese long snout catfish	17 (1)	17 (100)								0
Yellow catfish	184 (6)	184 (100)								0
Others	409 (13)									
TOTAL	**3 049**									
Indian major carp										
Rohu	1 167 (22)			313 (27)	254 (22)					600 (51)
Catla	3 870 (71)			3 598 (93)	196 (5)					75 (2)
Mrigal	379 (7)			164 (43)	149 (39)					65 (17)
TOTAL	**5 416**									

Note: nei = not elsewhere included.
Source: FAO (2012b).

The Indian major carps are mainly farmed in India, Myanmar and Bangladesh, with India accounting for 75 percent of world production in 2010. Catla was the most popular major carp (Figure 5). The production of catla reported since 2003 has increased dramatically and in 2010 accounted for 71 percent of all Indian major carp production (Table 2). India produced 93 and 43 percent of all reported global catla and mrigal production, respectively, in 2010 (Table 2).

2. PRODUCTION SYSTEMS AND CHANGES IN CULTURE PRACTICES IN SELECTED COUNTRIES AND SPECIES

2.1 Types of production systems

Aquaculture practices are now driven by the basic economic criteria of income generation. However, productivity and production (and therefore subsequent income of farmers) in many parts of the world are still governed by the balance between availability and affordability of production inputs, in particular aquafeeds, which typically account for 50–70 percent of production costs (Hasan, 2007; Hasan *et al.*, 2007). The increasing competition for common resources such as land and water is dictating a global trend of intensification in aquaculture production. The degree of intensification in countries varies, being governed by species, market price and available resources. These key trends are considered for freshwater finfish and shellfish species in the selected countries shown in Table 3.

TABLE 3
Geographic scope and species considered in this synthesis

	Bangladesh	China	India	Viet Nam	Thailand	Philippines	Egypt	Ghana
Nile tilapia		X			X	X	X	X
Major carps	X		X					
Striped catfish				X				
Whiteleg shrimp				X				
Black tiger shrimp			X					
Giant river prawns	X							

For all freshwater finfish species, pond culture is the most commonly used farming method in all countries, followed by cage culture (Table 4). Cage farming of tilapias is most prevalent in the Philippines and Egypt, accounting for 32 and 21 percent of national tilapia production, respectively.

TABLE 4
Types of production systems for selected countries and freshwater finfish species

Country	Bangladesh	India	Viet Nam	China	Thailand	Philippines	Egypt	Ghana
Species	**Major carps**	**Major carps**	**Catfish**	**Tilapia**	**Tilapia**	**Tilapia**	**Tilapia**	**Tilapia**
Cages			X		X	XX (32)[1]	XX (21)	X
Pond size range (ha)	0.13–0.80		0.30–0.33	0.30–3.30	0.1–5.0	1–3	0.5–3.0	0.1–0.5
Extensive	XXX	X		X	X		X	XXX
Semi-intensive	XX	XX		XX	X	X	XX	X
Intensive		X	XXX	X	XX	XX	X	X

[1]Number in parenthesis accounts for percent of national production.

Note: X = seldom used; XX = widely used; XXX = most commonly used farming method.

Typically, all ponds used for farming these freshwater species are relatively small (0.1–5 ha). In Bangladesh and Viet Nam, ponds are considerably smaller, at less than 1 ha (Table 4). Pond depths, however, vary considerably. Although ponds are generally about 1 m deep, catfish ponds in Viet Nam are typically 3–4 m deep, facilitating high production. In the last two decades, there has been a gradual shift from extensive to semi-intensive production of the Indian major carps and tilapias in most countries. Extensive farming practices, however, are still common in Bangladesh for Indian major carps and in Ghana for tilapia (Table 4). Catfish, on the other hand, are now mainly produced intensively in small but deep ponds yielding production in excess of 100 tonnes/ha (Nguyen, 2013).

Shrimps and prawns are exclusively farmed in small ponds (0.2–2.0 ha), with all countries except Viet Nam farming extensively and semi-intensively (Table 5). Whiteleg shrimp are mainly farmed intensively in Viet Nam, with yields of 20–40 tonnes/ha. On the other hand, in Bangladesh, giant river prawns are typically farmed extensively and semi-intensively in very small ponds (0.2–0.5 ha) with correspondingly lower yields of 0.35–0.7 tonnes/ha (Table 5). In India, black tiger shrimp are farmed extensively and semi-intensively in larger ponds.

TABLE 5
Types of production systems in selected countries for selected prawn and shrimp species

Country	Bangladesh	India	Viet Nam
Species	**Giant river prawns**	**Black tiger shrimp**	**Whiteleg shrimp**
Pond size (ha)	0.2–0.5	0.5–2.0	0.3–0.6
Extensive (yield – tonne/ha)	XXX (0.35)	XX (0.5)	–
Improved extensive (yield – tonne/ha)	XX (0.5)	XX (1–2)	X
Semi-intensive (yield – tonne/ha)	XX (0.7)	XX (2–4)	
Intensive (yield – tonne/ha)			XXX (20–40)

Note: XXX = predominant type; XX = commonly used; X = seldom used.

2.2 Brief summary of change in culture practices

The trigger for change in culture practices is market opportunity combined with the need for increased production and productivity while ensuring the delivery of required environmental services for aquaculture. A varying combination of technological advances and effective knowledge transfer, access to natural resources, and state intervention in the reference countries created country-specific opportunities to change culture practices. In common for all countries, the key technological drivers and milestones significantly directing these farming practice changes were the successful closure of the Indian major carps and striped catfish breeding cycles and the mass production of seed, creating the platform for expansion and change.

2.2.1 Indian major carps (Labeo rohita, Catla catla and Cirrhinus cirrhosus)

As the largest producer of Indian major carps, India has set the pace for change and innovation in culture practices since the 1960s. The successful artificial breeding of major carps through hypophysation in 1957 transformed and facilitated expansion of Indian carp culture from small backyard ponds in the eastern Indian states of West Bengal, Orissa and Bihar to significant commercial-scale operations in states such as Andhra Pradesh, Punjab, Haryana, Karnataka and Tamil Nadu.

In addition, three prominent factors governed and facilitated the pace of change in Indian major carp culture practices and expansion:

- the concerted demonstration effort by government of the composite culture of Indian major carps and Chinese carps through Fish Farmers Development Agencies located throughout the country;
- the ease of paddy conversion to ponds using flood water and saline waters;
- the deceasing net returns from paddy crops.

Andhra Pradesh, which in 2008 accounted for 30 percent of national Indian major carp production, was the central state in developing local innovative changes to basic polyculture practices resulting in new opportunities in the production value chain. The composite culture of carps initially practised in the 1980s using small (5–10 g) Indian major and Chinese carp fingerlings and 5–7 tonnes of supplementary feed often produced undersized fish (<500 g), arising from premature harvesting owing to poor pond conditions. These fish, known as "zero fish", typically fetch less than one third to half the price of normal market-sized fish (1–2 kg). These zero fish created a new farming segment, as innovative farmers bought these as stocking material for on-growing to acceptable size in just six months, thus halving the growing period. This, together with the exploitation of compensatory growth response in fish, resulted in creating a new subsector for the semi-intensive polyculture industry using major carp juveniles of 50–125 g. Thus, composite extensive backyard carp polyculture has evolved over two to three decades into semi-intensive carp polyculture by stocking predominantly larger major carp yearlings, yielding 8–10 tonnes of fish using 23–28 tonnes of supplementary feed. Such changes in culture practices are also mirrored in Bangladesh. Market opportunities in both India and Bangladesh created impetus for further changes in culture practices as farmers introduced a larger species mix into this farming system. In India, Indian major carps have been reared in mixed semi-intensive culture with black tiger shrimp, striped catfish, giant river prawns and pirapatinga (*Piractus brachypomus*) since 1990, 1995, 2000 and 2008, respectively.

2.2.2 Nile tilapia (*Oreochromis niloticus*)

The Nile tilapia is principally farmed in ponds in China and Thailand, and in addition in cages in lakes in the Philippines, Egypt and Ghana. Intensification through the use of larger fingerlings (50 g), aeration, increased feed inputs and a shift to culture in cages have characterized the changes in tilapia culture practices in these countries. The reasons for the shift and scale of change have varied depending on the phase of national aquaculture development.

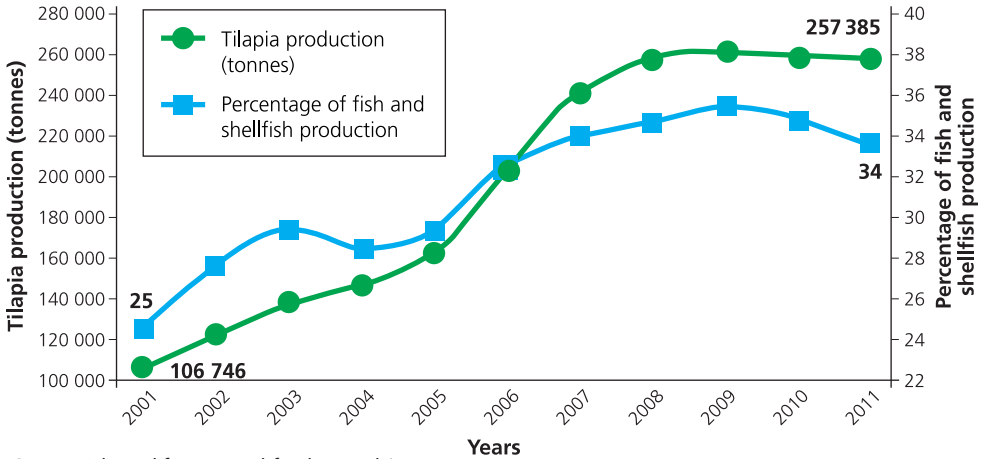
Although China has farmed Mozambique tilapia (*O. mossambicus*) since 1950 in traditional integrated production systems with carps, this species was not in high demand owing to its relatively high cost and poor growth rate. However, the open-door policy, sharply rising living standards of the 1980s and a switch to farming Nile tilapia provided the impetus for a dramatic increase in production, especially in the provinces of Guangdong and Hainan, which accounted for about 66 percent of Chinese tilapia production in 2010 (Liu *et al*., 2013). Although polyculture is still a common practice among small-scale farmers (typically 2–4 ha) with limited capital investment, tilapia farming has evolved to take advantage of increasing demand and better prices. Typically, tilapia was used as a minor component in polyculture with carps, yielding about 2 500 kg/ha tilapia, but this changed as many farmers reversed culture practice to make tilapia the major stocked fish, with yields of 7–8 tonnes/ha using in-pond aerators and pelleted feeds. This shift also created new opportunities within the production value chain for dedicated broodstock and fingerling and yearling (overwintered) seed production farms. Good prices and demand also spurred a shift from traditional polyculture to monoculture, on-growing fingerling and yearling tilapias using multiple cropping systems. Larger commercial farms (typically, 20–30 ha), with substantial local investment, local government support and attracted inward investment, began to farm tilapia intensively in the 1990s using larger, deeper ponds, aerators, automated feeders and extruded pellets, with yields

of up to 15 tonnes/ha (Liu *et al.*, 2013). Culture practices were further influenced by the availability of warm spring water and heated water from power stations, allowing tilapia to be farmed intensively in the colder northern provinces such as Beijing.

Tilapia did not feature in statistics for the Philippine until the 1990s, as its production from freshwater and brackishwater ponds, cages and pens increased in significance. The contribution of tilapia to total fish and shellfish production from these production systems almost doubled over the decade, increasing from 25 percent (107 000 tonnes) in 2001 to 34 percent (257 000 tonnes) in 2011 (Figure 6). The main change in tilapia farming practices in the Philippines was characterized by a shift in choice of the tilapia species farmed in the 1970s from *O. mossambicus* to *O. niloticus*. Irrespective of species farmed, the typical market size of tilapias is much smaller, at 200–250 g, compared with other regional countries such as China. From the late 1980s, increased production of Nile tilapia in the Philippines was further aided by the use of hormonally manipulated tilapias and genetically improved strains (e.g. GIFT). By this millennium, more than half of the farmers were using genetically enhanced stock. Tilapia culture using recent innovations and saline-acclimated Nile tilapia has also gained from the idle and underutilized brackishwater shrimp (and milkfish) ponds this millennium arising from disease outbreaks. Taking advantage of niche market opportunities for organic produce also further changed culture practices with the use of all-natural inputs in each phase of the operation. The eutrophic inland water bodies such as Laguna Lake made possible the use of pens and cages for tilapia culture using minimal inputs for fingerling and on-growing production. The increasing switch to higher stocking densities in cages (up to tenfold) and the use of commercial feed in the last decade has increased unit production 5–6-fold over semi-intensive culture (Romana-Eguia, Laron and Catacutan, 2013). Finally, the demand for tilapia in the export market has attracted some Philippine farmers to engage in the production of export-size tilapia. The method used normally requires stocking and feeding advanced tilapia fingerlings of 50 g (compared with the normal 10–20 g size) with complete commercial diets until the fish reach 750–800 g.

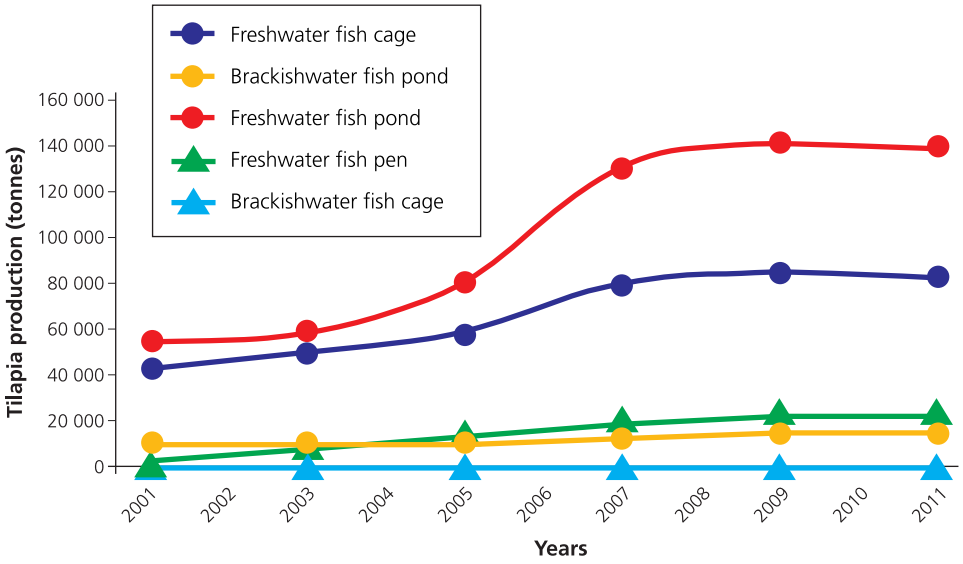
Overall, production has increased, spurred by formulated diets and larger fingerlings of improved stock; however, growth has not been linear, probably being affected by natural-resource limitations. In this millennium tilapia production increased linearly to about 2007 but has since plateaued. The greatest increase in tilapia production originated from freshwater ponds, followed by freshwater cages up to 2007 (Figure 7). Production from brackishwater and marine areas has been limited, but any further increase in tilapia production may be expected from these environments.

FIGURE 6
Changes in contribution of Nile tilapia to total fish and shell fish production in the Philippines



Source: Adapted from www.bfar.da.gov.ph/

FIGURE 7
Changes in contribution of Nile tilapia production from freshwater and brackishwater ponds, cages and pens in the Philippines



Source: Adapted from www.bfar.da.gov.ph/

As in the Philippines, tilapia farming in Thailand began in the late 1950s and since then, its culture has gradually moved from extensive to semi–intensive pond culture. Although a large majority of farmers still farm semi-intensively in ponds, there was a trend towards intensive farming in cages in rivers; but owing to pollution risks, some farmers, recognizing the benefits of cage culture, switched to siting cages in large ponds. Opportunities for intensification of tilapia production were made possible by feed companies that entered into contract farming, providing feed with a buy-back scheme in the late 1990s. The provision of feed by feed companies on a credit scheme made possible the sole use of commercial feed using larger fingerlings (30–50 g) to achieve two crops of fish per year with yields of 50 kg/m^3 crop of fish averaging 900–1 000 g (Bhujel, 2013).

Tilapia culture practices in Africa are also undergoing changes to meet the challenges of increasing demand. With tilapia prices rising, there is greater investment is countries such as Egypt and Ghana.

In contrast to Asia, Egypt traditionally utilizes brackishwater ponds to farm tilapia in polyculture with carps and mullets. Since the late 1990s, however, the value of tilapia has increased, and this system has been gradually replaced with semi-intensive monoculture of tilapia stocked at 12 000–40 000 fish/ha in earthen brackishwater ponds. With the advent of all-male Nile tilapia fingerlings, more than 75 percent of farmers switched over to mono-sex farming of tilapias. By 2008, more than 80 percent of tilapia were produced in semi-intensive systems (El-Sayed, 2013). By 1999, the number of fish farms utilizing intensive pond culture techniques had increased to 68, covering a total area of 1 088 ha. This created a new and growing demand for large tilapia fingerlings (especially monosex tilapia) and pelleted feed (both extruded and expanded). In less than six years, the number of fish hatcheries increased from 28 freshwater fish hatcheries to more than 350 hatcheries in 2009 (FAO, 2003–2013).

The use of ground water in the desert for integrated tilapia culture is a new feature of Egyptian aquaculture this millennium. Desert land owners rear fish in the tanks used as water reservoirs for irrigation. With continued government technical support, farmers have brought integrated fish farming into their agribusinesses, producing more than

1 000 tonnes of tilapia. With government support, this trend is expected increase to several hundred of such farms within five years. Good economic returns have also resulted in Egyptian farmers progressing to intensive tilapia farming in ponds and cages. Under intensive conditions, ponds are aerated with air compressors or paddles, stocked at 50 000–100 000 fish/ha and commercial feeds applied. The fish reach 200–250 g in 7–9 months, with a total yield of 12–25 tonnes/ha.

The use of cages of varying sizes (30–600 m^3) in rivers, especially in the northernmost branches of the Nile Delta, has also gained momentum in the last decade. While in 1993, only 355 cages were in operation, there are more than 4 500 cages in use. Annual production from cages increased 49 percent per year, rising from 12 900 tonnes in 1999 to reach 69 108 tonnes in 2008. In recent years, some farmers in Egypt have invested in intensive culture of tilapia in concrete tanks under greenhouses (Figure 8), especially in arid and semi-arid areas where freshwater or brackishwater is limited. Most tilapia farmers raise all-male Nile tilapia in aerated tanks stocked at 25–100 fish/m^3 fed on commercial floating pellets for 6–9 months with yields of 10–30 kg/m^3 of 200–400 g/fish.

FIGURE 8
Tank culture of Nile tilapia in Kafr El-Shaikh, Egypt

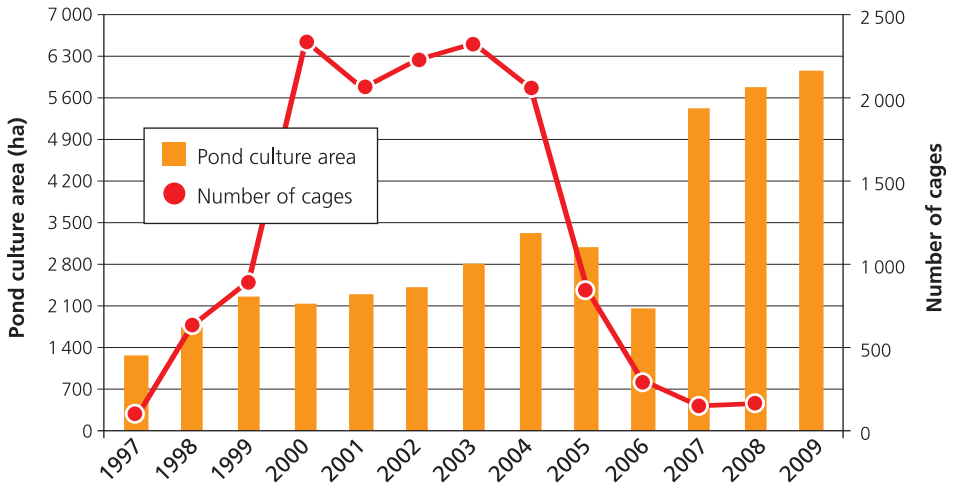
COURTESY OF FAO/A.-F.M. EL-SAYED.

Ghana has typically farmed tilapia extensively in household ponds since the 1950s and to some extent under semi-intensive conditions using supplementary feeds. With market prices exceeding US$3/kg, farmers in Ghana targeted the intensification of tilapia culture, with the first cage farm being established in the late 1990s and the second in 2005 on Lake Volta. Locally made cages are stocked in a two-stage system, initially with fish weighing 5–8 g at 100 000 fry/cage. When they reach 40–50 g (2 months), they are transferred to other cages at half the stocking density and reared to a selling size of 250 g (2–3 months). Since 2005, cage-culture technologies have been developed for smallholder farmers. Typically, these cages (50 m^3) are stocked with 3 000–9 000 fingerlings of 10–30 g and fed on pelleted diets for 5–7 months.

2.2.3 Striped catfish (*Pangasianodon hypophthalmus*)

Viet Nam is the epicentre of Asian and global catfish culture, the practice of which was transformed in 2000 with the all-year-round availability of seed and a shift in cultured species and production system. Two species have dominated catfish culture in Viet Nam since the 1960s, "basa" (*Pangasius bocourti*) reared in cages and pens, and striped catfish or "tra" (*Pangasianodon hypophthalmus*) reared in ponds using traditional farming methods. Beginning in the mid-1990s, however, cage and pen culture practices declined, and then collapsed after 2004 (Figure 9), primarily owing to the cost of cages, poor growth performance, and increasing mortalities and disease outbreaks compared with pond culture (Nguyen *et al.*, 2004; Nguyen and Dang, 2009). The culture of striped catfish in small farms (<5 ha) using small (0.4 ha), deep (3.5–4.5 m) ponds predominated (Phan *et al.*, 2009), the total area of which had increased to 5 800 ha by 2008 (Figure 9). Since 2000, the farming practice has been characterized by a switch from farm-made pellets to complete commercial extruded diets (Nguyen and Dang, 2009).

FIGURE 9
Changes in production systems used for farming striped catfish in Viet Nam



Source: Nguyen (2013).

2.2.4 Giant river prawns (*Macrobrachium rosenbergii*)

In the last three decades, the farming of giant river prawns (*Macrobrachium rosenbergii)* has attracted considerable attention because of export potential. About 14 percent of the global production originates from Bangladesh. In this country, farming giant river prawns is a widespread small-scale activity where farmers integrate rice culture with rearing mainly wild-caught prawn postlarvae (PL) in small (0.2 ha) paddy fields. Inputs are limited and feeding is often characterized by the capacity of resource-poor farmers to procure feeds (mainly snail meat), with prawn yields of 350 kg/ha. In the 1990s, however, the high international prices and availability of hatchery-reared PL encouraged many small to medium-sized farmers to change their culture practice to focus only on farming in larger ponds (0.2–0.4 ha) using supplementary feeds, with yields of about 500 kg/ha. Rice fields were converted by raising the water dykes or bunds to deepen ponds and installing a deep channel to hold water during the dry season, a practice known as *gher* farming. The high returns have also attracted investment, and larger semi-intensive farms have been established since the mid-1990s using industrial feeds, with yields of 700 kg/ha. In all farming systems, mortalities were high and in the last few years farmers have introduced a nursery phase in ponds whereby PL are reared in hapas for 4–6 weeks before being introduced into ponds.

2.2.5 Black tiger shrimp (*Penaeus monodon*)

Asia is the most important shrimp-producing region of the world in terms of farmed black tiger shrimp output, with Viet Nam (43 percent), Indonesia (16 percent), India (12 percent), China (7 percent), Bangladesh and the Philippines (6 percent each) sharing most of the global production (Table 2).

The great bulk (90 percent) of shrimp farming in India is based on the extensive farming system. In recent years and particularly since the 1990s, there has been a trend towards increased intensification. Extensive and modified extensive farms are shifting towards semi-intensive farming of shrimps. For better management, pond units are much smaller (0.1–1.0 ha) but deeper (1.5–2.0 m). Stocking density ranges from 100 000 to 200 000 PL/ha per crop, with crop yields of 3–5 tonnes/ha using complete artificial feeds, increased aeration and intensive monitoring.

2.2.6 Whiteleg shrimp (Litopenaeus vannamei)

Following the downturn in black tiger shrimp production in the late 1990s owing to disease outbreaks, whiteleg shrimp offered an acceptable substitute, and by 2010 it was the dominant shrimp species, with a global production of 2.7 million tonnes. Although farmed illegally in Viet Nam since 2000, the Government of Viet Nam allowed the culture of whiteleg shrimp in the Mekong Delta in 2006. Hence whiteleg shrimp culture is relatively new in Viet Nam. In the last decade, farms have mainly practised intensive culture using commercial feeds and stocking densities of 100–200 hatchery-reared PL per square metre, but avoiding the use of fertilizers. The majority of farms are less than 1 ha in size, typically, less than 0.3 ha.

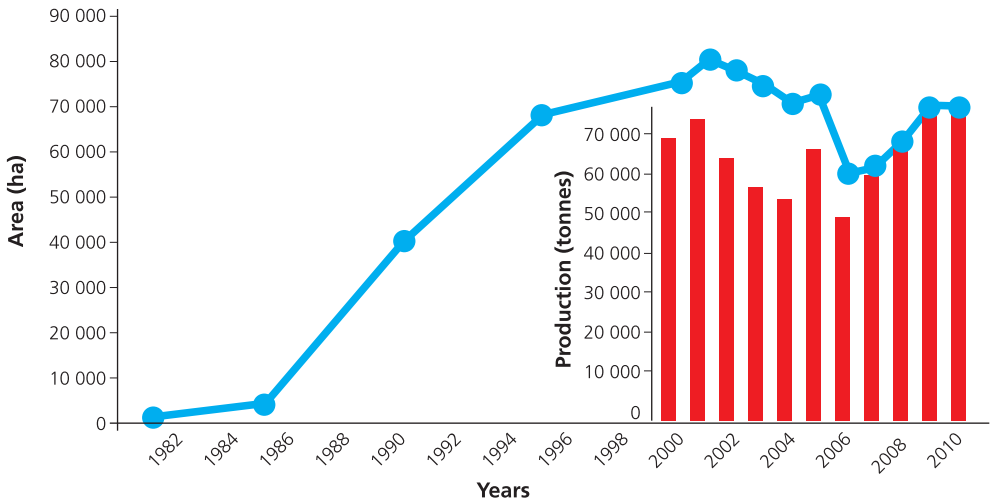
3. UTILIZATION OF AQUAFEEDS

3.1 Implications of diminishing resources for aquafeeds and feed management

Feedback from farmers in all case studies considered in this synthesis points to a varying degree of intensification to increase production volume and efficiency, this increase being principally achieved through using larger fingerlings, deeper ponds and varying levels and quality of supplementary or complete feeds. At a national level, however, improved production efficiencies and increased production are fast becoming a necessity to ensure national food security. In an environment of diminishing natural resources and rising costs, governments will have to develop policies specifically focusing on sustainable productivity, as countries already show resource-limited production.

Expansion of aquaculture in India, especially in key states such as Andhra Pradesh, may be limited by natural resources. The production of major carps in Andhra Pradesh follows and is capped by the area of ponds under cultivation (Figure 10). Under such conditions increases in production can only be achieved through improved productivity.

FIGURE 10
Estimated changes in area used to culture Indian major carps in Andhra Pradesh from 1981–2010 in relation to production



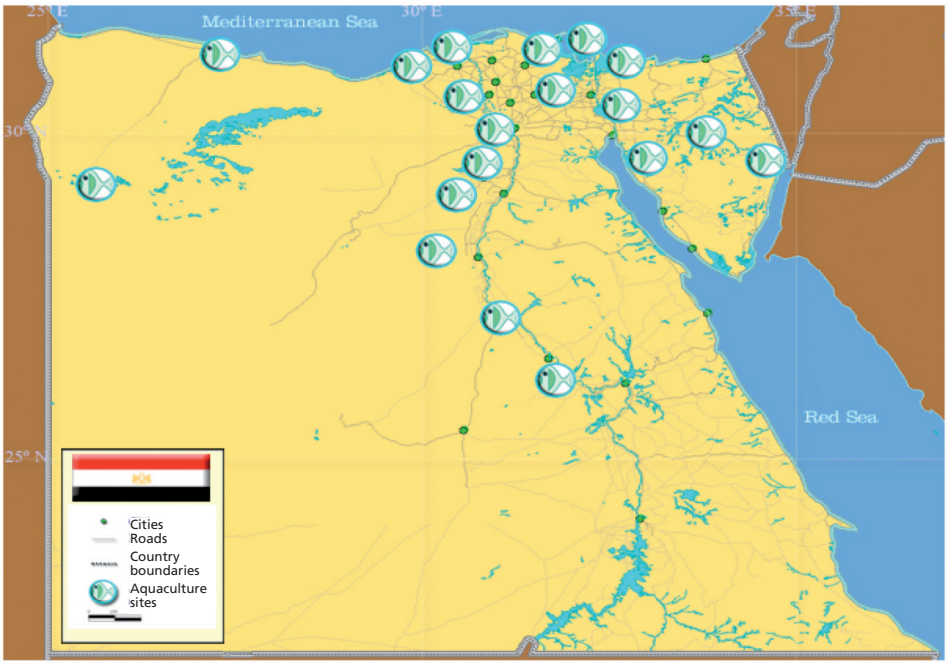
Source: Adapted from Ramakrishna, Shipton and Hasan (2013).

The area dedicated to the culture of Indian major carps plateaued at 80 000 ha in 2000 (Figure 10). Opportunities for expansion into new species, however, were confined to this area. During the expansion of catfish culture, 10 000 ha of ponds originally used for Indian major carps were converted for mono or mixed culture of striped catfish,

which were introduced to Andhra Pradesh in the mid-1990s from Bangladesh *via* West Bengal State, India. Thus the culture area for Indian major carps was reduced to an estimated 70 000 ha. Currently, the total area in the state devoted to striped catfish is estimated to be 20 000 ha and is increasing at the expense of Indian major carps (Ramakrishna, Shipton and Hasan, 2013). In such circumstances, if additional land is not made available, farmers are likely to make an economic decision on the species to be farmed based on returns; traditional species are likely to be compromised or have their production intensified to secure greater returns. Such an approach will also require financial incentives from government. To meet this challenge, the Indian National Fisheries Development Board (NFDB) was established in 2006 under the administrative control of the Department of Animal Husbandry to empower all Indian states and union territories to promote aquaculture and provide financial support, mainly through subsidies for other feed inputs and on-farm feed production.

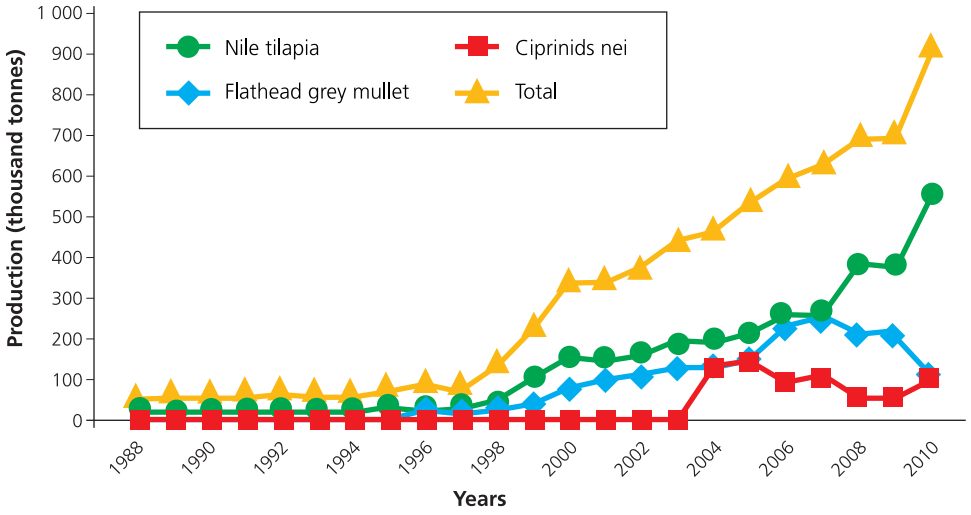
The availability of land and water is also a significant challenge in Egyptian aquaculture, with available areas showing saturation. Most aquaculture activities are located in the northern Nile Delta region, with fish farms clustered in the areas surrounding the four delta lakes (Maruit, Edko, Boruls and Manzala) and along the Nile River (Figure 11). Expansion in most of these areas is constrained by the lack of sites for land-based aquaculture and conflicts over water use. Despite water limitations and most of the land suitable for pond aquaculture being already in use, the target of the government to produce 1.5 million tonnes/year by 2017 is expected to be reached by converting traditional farms to intensive pond-culture systems. Within this paradigm, the competition for space and resources may also be reflected in the choice of species cultured. In recent years, there has been a shift from cyprinids to tilapias, as farm practices switch from polyculture to monoculture. In the last reporting year, this trend was also seen for mullets. In the last ten years tilapia production increased dramatically from 157 000 to 557 000 tonnes (Figure 12). In addition to natural resource constraints, these shifts in culture practices are also influenced by rising feed prices and lower market fish prices (Rana, Siriwardena and Hasan, 2009).

FIGURE 11
Geographic distribution of aquaculture production sites in Egypt



Source: Adapted from FAO (2003–2013).

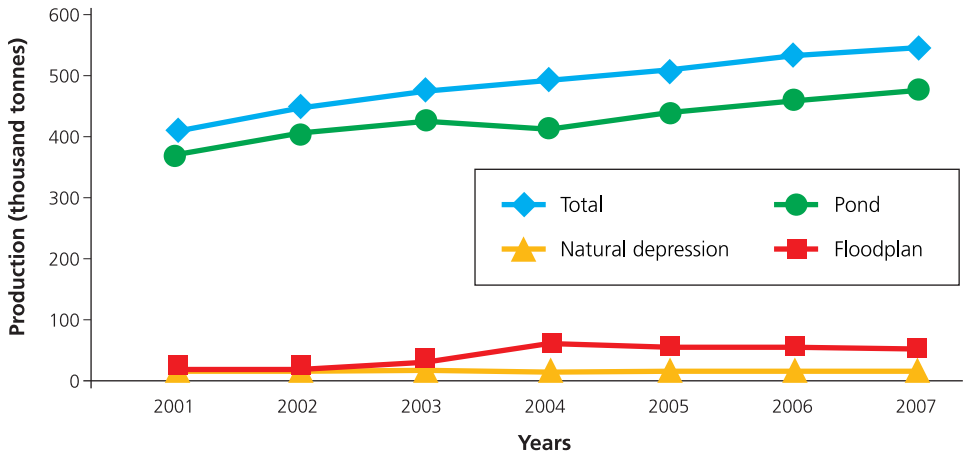
FIGURE 12
Changes in species cultured as sites in Egypt became limiting (1988–2010)



Source: Adapted from FAO (2012b).

Notable strains on farming systems and land resources are also evident in Bangladesh. Ponds are the predominant method of production, followed by floodplains and natural depressions (Figure 13). However, production from ponds has only increased by 5 percent annually in this millennium, and it actually decreased by 1–4 percent per year between 2004 and 2008 for production from floodplains and natural depressions (Figure 13). Fragmentation of landholdings for cultural reasons has significantly increased the number of small farms. Prawn farms average 0.31 ha compared with 0.60 ha for rice-only farms. With the increase in population, the average size of rice farms declined from 1.43 ha in 1961 to 0.87 ha in 1994, and is now just 0.60 ha (Rahman and Parkinson, 2007). Prawn farms were also larger more than a decade ago, averaging 0.35 ha. The reduction in pond size will inevitably result in a lower pro-rata net income for resource-poor farmers, and this calls into question the sustainability of such activities. Increased productivity through better feeds and feed and pond management practices is therefore imperative.

FIGURE 13
Temporal changes in production from different resource types used for aquaculture in Bangladesh



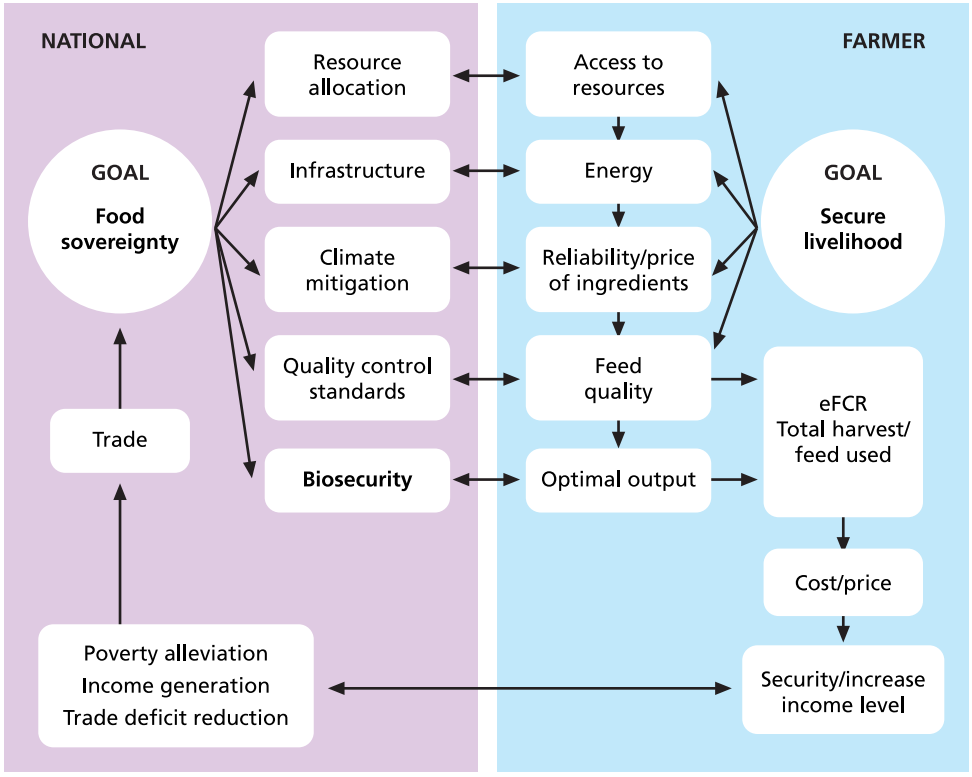
Source: Adapted from Sarder (2013).

3.2 Improving production volumes and efficiencies

3.2.1 Relationships between national and farmer aspirations

Government and individual farmers will have synergetic roles in contributing to increased aquaculture output, with government taking the lead role to address capacity and constraints to improve efficiency through prioritized research and development with measurable impacts. The key issues and roles of government that will affect farmers, especially as they relate to feed inputs, are highlighted in Figure 14. In order to address the national goal of food security, governments will have to put in place measures to secure and increase natural resources, improve farmer access for aquaculture and improve infrastructure to minimize the transaction costs of farmers while ensuring fair prices for energy that will be increasingly required to raise productivity. Securing aquafeed ingredients, either through increases in domestic production or by increased imports, will be key to future development of aquaculture, while quality control of manufactured feeds will be crucial to ensuring optimal use of feed ingredients. To maximize outputs, governments and farmers alike will have to put in place improved pragmatic management practices to reduce mortality.

FIGURE 14
Interrelationships between national roles and farmer aspirations to address aquaculture production constraints



Source: Compiled by authors.

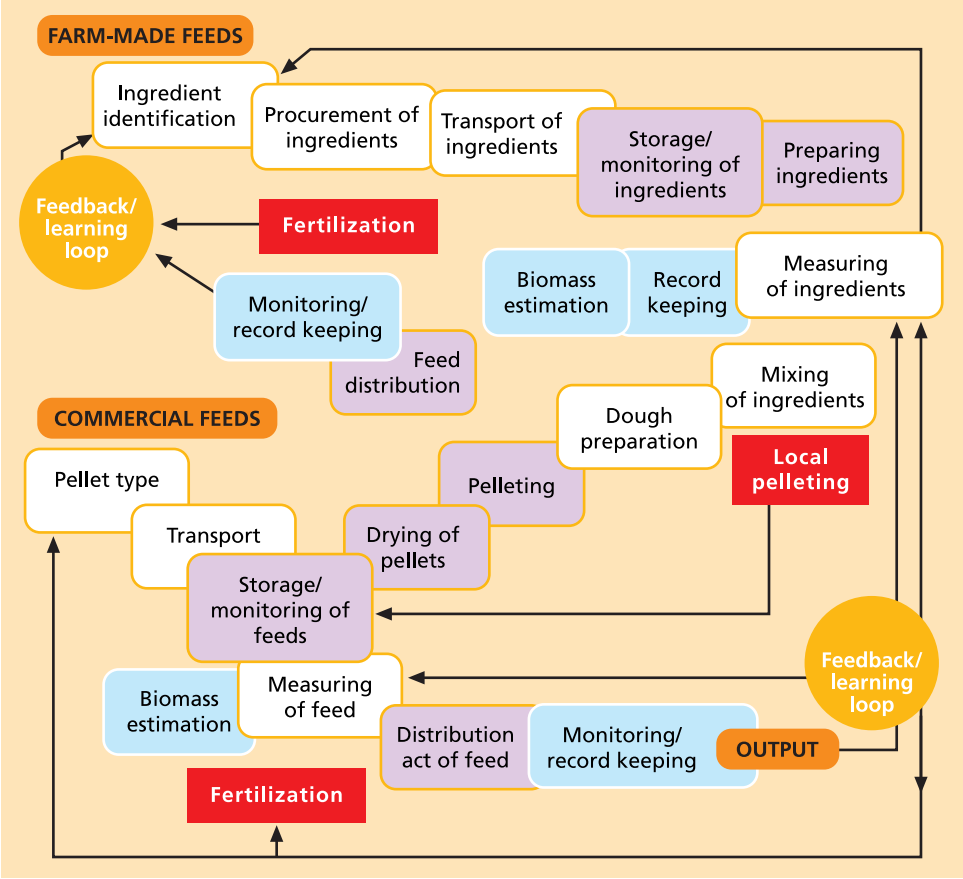
3.2.2 Use and management of on-farm feeds in selected countries

Farmers in the survey countries (Bangladesh, China, Egypt, Ghana, India, the Philippines, Thailand and Viet Nam) deploy a spectrum of practices for securing aquafeeds. Aquafeeds may be prepared with procured or home-grown ingredients on the farm or bought as complete manufactured feeds. Farmers deploy a range of options to secure aquafeeds. Farmers that make their own farm-made feeds often buy

ingredients from local suppliers. These ingredients are transported to the farm site where they are milled, if required, or taken to local millers who prepare the ingredients for inclusion in diets. Depending on resources, farmers may distribute these ingredients as a powdered diet, but this practice is fast dwindling as farmers mix ingredients with water to produce dough balls; these are fed directly to fish either on trays or dispersed over ponds (e.g. major carps in Bangladesh) or pelleted in a simple pelletizer, the pellets then being air dried, stored and fed as required (Figure 15).

Where resources or credit facilities are available, farmers prefer to use commercially manufactured sinking or floating pelleted aquafeeds. In countries such as Egypt, 40 percent of the farmers surveyed used extruded feeds, often using demand feed dispensers.

FIGURE 15
Composite of specific components of on-farm feed production and management chain



Source: Compiled by authors.

3.2.3 Significance of feed cost

The use of concentrated feed in the form of floating or sinking pellets has been the key contributory factor to increased production, together with aeration and improved water management. In the last two decades, however, the price of ingredients has multiplied and significantly affected aquafeed prices. These impacts and consequent challenges for the sustainability of aquaculture have recently been reviewed by Rana, Siriwardena and Hasan (2009).

In a context of increasing feed and production costs, feed utilization efficiency is of paramount importance. The contribution of feed as a proportion of production cost

is typically greater than 50 percent, irrespective of scale or intensity of production (Table 6). In China, where tilapias are cultured as the major crop in polyculture or intensive monoculture, feed accounts for 70–80 percent of production costs. Similarly, in Viet Nam feed contributes more than 80 percent of production costs for striped catfish production. Overall, the proportional cost of feed was lower when farm-made feeds (FMFs) were used. In India, where FMFs were used for Indian major carps, feed costs were below 60 percent. Similarly, for giant river prawns in Bangladesh, the use of on-farm feeds maintained feed costs below 35 percent. Irrespective of intensity of stocking or species, the use of commercial feed increases feed contribution to production costs. Although black tiger shrimp were farmed extensively in India, the use of commercial feeds increased feed costs to about ~60 percent of production costs (Table 6). In all scenarios, feed is the single most important production cost item; therefore, any management interventions to reduce feed input costs will have a significant bearing on the sustainability of aquaculture operations.

TABLE 6

Cost of feed as percentage of production cost for selected countries and pond-cultured species

Country	Species mix	Production system	Feed as % of production cost	Yield (tonnes/ha)	Source
Finfish					
China	Tilapia	Ponds – tilapia main crop polyculture + commercial feeds	68–84	7–9	Liu *et al.* (2013)
		Ponds – monoculture + commercial feed		8–12	
Philippines	Tilapia	Ponds – monoculture + commercial feed	50–60	7–15	Romana-Eguia, Laron and Catacutan (2013)
		Ponds – monoculture Farm-made +commercial feed		1–3	
Viet Nam	Striped catfish	Monoculture + commercial feed	83	325	Nguyen (2013)
		Monoculture + farm-made feed	77	398	
India	Indian major carps	Typical Indian major carps- mash	54	7	Ramakrishna, Shipton and Hasan (2013)
		Zero point culture – Indian major carps	48	5–6	
		Zero point culture – Indian major carps-mash-pellet	49	–	
		Zero point culture –Indian major carps-mash	41	–	
Shrimps and prawns					
Viet Nam	Whiteleg shrimp	Monoculture + commercial feed	66–69	9–15	Hung and Quy (2013)
Bangladesh	Giant river prawns	Extensive + snail meat	15	0.35	Ahmed (2013)
		Improved extensive + farm-made aquafeed	25	0.48	
		Semi-intensive + commercial feed	33	0.72	
India	Black tiger shrimp	Extensive + farm-made feed	52	0.38	Ramaswamy, Mohan and Metian (2013)
		Modified extensive Commercial feed + farm-made feed	59	1.3	
		Semi-intensive Commercial feed	62	2.8	

3.2.4 Risk options for farmers

Nations will have to prioritize how their resources are used. In the case of aquaculture, governments have two options to increase output: increase land and water area under cultivation; and/or increase unit productivity. An evaluation of the case studies suggests that farmers are faced with increasing uncertainty of feed price rises and limiting natural resources; consequently, farmers are intensifying production as one means of mitigation. However, the benefit-cost ratio (BCR) of aquaculture operations can be similar irrespective of feeding regime (Table 7) or intensification (Table 8). In India, the BCR ranged from 1.2 to 1.3 despite the use of improved feeds. In the case of Bangladesh, this ratio was greater, at 1.7–1.8, due to the higher price of prawns irrespective of intensification. Similarly, for semi-intensive culture of whiteleg shrimp in Viet Nam, the BCR was 1.6–1.7 (Hung and Quy, 2013). These data suggest that neither intensification, feed quality nor feed management by themselves necessarily increase returns on investment, yet where possible, farmers have intensified. The principal likely driver therefore for the increase in absolute net income is increase in farm size. For example, in Bangladesh, although the BCR was similar for extensive and semi-intensive culture, increasing farm size with intensification from 0.2 to 0.5 ha more than doubled annual net income from US$1 000/ha to US$2 100/ha (Ahmed, 2013). Data also suggest that increasing farm size and feed input may not necessarily result in increased unit returns.

TABLE 7

Benefit-cost ratio for culture of Indian major carps in India under various feed management conditions

Parameters	Zero point Indian major carp culture			
	Typical mash	Mash	Mash + pellet	Pankaj – mash
Annual net income (US$)	1 129	495	2 020	3 061
Annual net income (US$/ha)	1 505	914	3 730	5 247
Benefit-cost ratio	1.2	1.1	1.3	1.3

Source: Adapted from Ramakrishna, Shipton and Hasan (2013).

TABLE 8

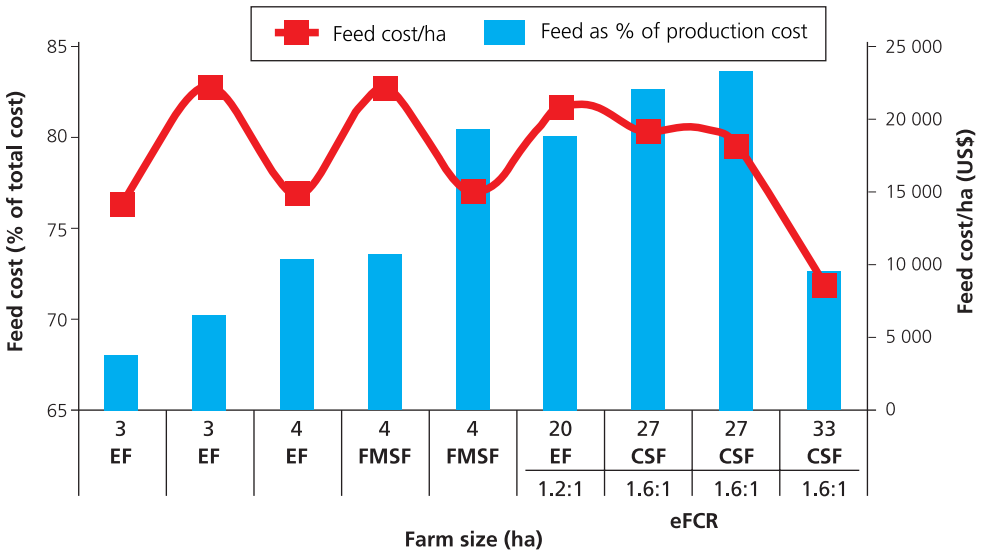
Benefit-cost ratio for giant river prawn culture in Bangladesh under varying intensification conditions

Parameters	Extensive	Improved-extensive	Semi-intensive
Annual income (US$/ha)	1 092	1 445	2 162
Benefit-cost ratio	1.7	1.7	1.8

Source: Adapted from Ahmed (2013).

In China, economic data suggest that larger intensive monoculture farms may not necessarily be as efficient as smaller polyculture units, and that larger farms could comprise feed management by virtue of their size (Figure 16). As farm size increased from 3 to 33 ha, the proportion of feed to total production cost increased, with one exception (33.3 ha), from 68 to 84 percent, showing no meaningful economies of scale. The per-hectare feed costs were similar, ranging from US$14 000 to 22 000/ha, with one exception. Increasing farm size was also not translated into improved feed conversion efficiencies of 1.6:1 (Figure 16).

FIGURE 16
Relationship between farm size, feed cost and feed utilization in China

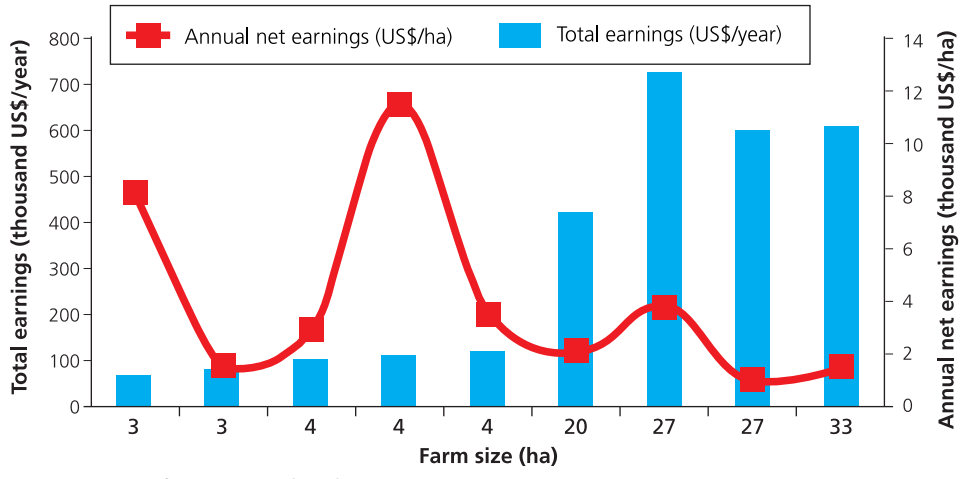


Source: Adapted from Liu *et al.* (2013).

Notes: EF = extruded feed; FMSF = farm-made sinking feed; CSF = commercially pelleted sinking feed; eFCR = economic feed conversion ratio. The feed conversion ratio is the ratio between the dry weight of feed fed and the weight of yield gain. It is a measure of the efficiency of conversion of feed to fish (e.g. FCR = 2.8:1 means that 2.8 kg of feed is needed to produce 1 kg of fish live weight). Two additional terms are used by the farmer, the biological FCR (bFCR) and the economic FCR (eFCR). The bFCR is the net amount of feed used to produce 1 kg of fish, while the eFCR takes into account all the feed used, meaning that the effects of feed losses and mortalities, for example, are included (adapted from FAO, 2010).

The larger, more intensive farms in China also did not necessarily translate into increased unit income (Figure 17). Although farms smaller than 4 ha showed a large range, their annual average earnings were US$8 400/ha compared with only US$2 000/ha for farm sizes between 20 and 33 ha, and larger farms showed no benefits, instead spending 2–4 percent of production costs on drugs and feed additives. Overall, the data suggest that increased income was attained by having a larger number of ponds and farm size rather than through improved production efficiencies.

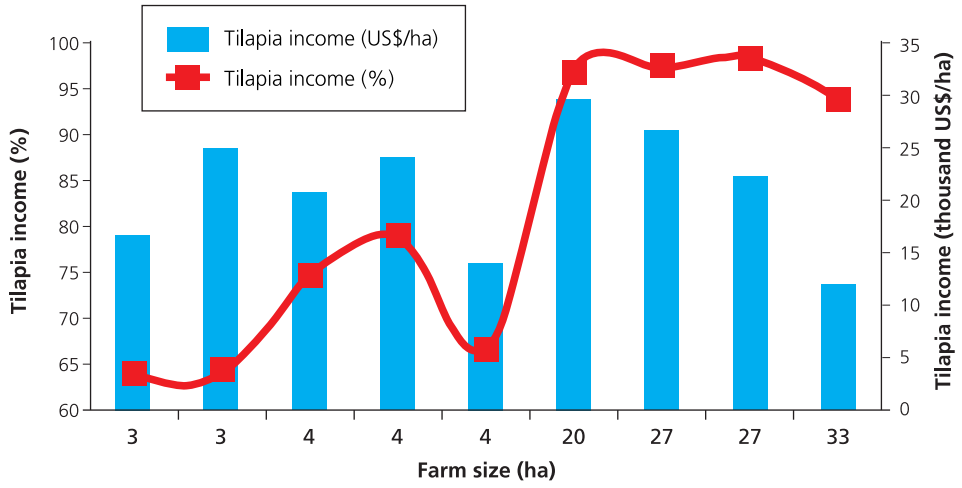
FIGURE 17
Relationship between Chinese farm size and total and unit area income



Source: Adapted from Liu *et al.* (2013).

The proportion of income from tilapia by farms of varying size is given in Figure 18. The contribution of tilapia income to farm income varied with type of production system and farm size. Farms of 4 ha and smaller adopted polyculture, a method in which tilapia was the main species, contributing 63–68 percent of total income. In the larger monoculture tilapia farms (> 20 ha), tilapia accounted for 94–97 percent of farm income. When the total farm revenue is considered, however, unit income decreased as farm size increased, while in smaller farms revenue from tilapia was similar (Figure 18). Overall, the Chinese experience points to larger monoculture farms being more inefficient, and increase in income is achieved by increasing farm size; this questions the resilience of the farming systems as currently managed.

FIGURE 18
Effect of increasing farm size on income from Nile tilapia in China



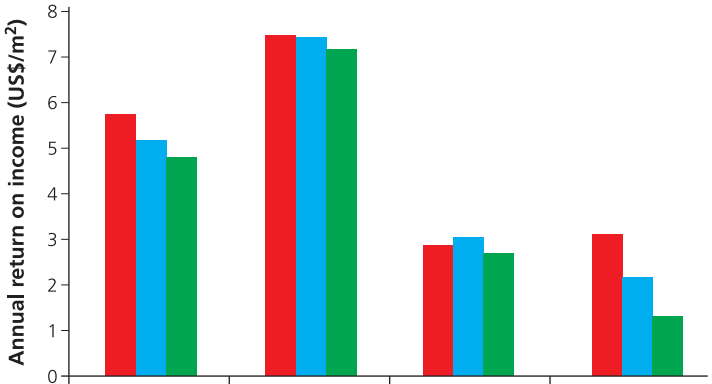
Source: Adapted from Liu *et al.* (2013).

3.2.5 Resilience of farming system to uncertainty of natural resources and feeds

Resource-poor farmers have limited capacity and resources to procure commercial feeds or to buffer themselves against escalating prices. Their ability to increase their net income from their aquaculture operations and to raise productivity is curtailed by virtue of their small farm size and limited capacity to secure finance. In countries such as Bangladesh, farms that are typically less than 0.3 ha are becoming smaller through subdivision when the land is transferred from parents to their children. Under these conditions, diversifying food production is a necessary livelihood strategy for sustained income. In this scenario, farmers have adapted, using local resourcefulness and knowledge, to stabilize and secure production (e.g. use of snail meat in Bangladesh). In addition, to increase net income from their small operations, farmers have switched to higher-valued species. In Bangladesh, for example, rice farmers have focused on rearing giant river prawns with fish and rice to successfully raise income and spread risk, the extent of increased production being feed-dependant. Nevertheless, 80 percent of farmers still farm using extensive (50 percent) or improved extensive (30 percent) methods with snail meat and farm-made feeds to earn between US$190/year (US$1 000/ha per year) and US$420/year (US$1 500/ha per year), respectively (Ahmed, 2013). The case study from Bangladesh also suggests that larger, more intensively farmed operations using commercial feeds are at best similar or poorer than extensively farmed operations and that increases in absolute income were achieved simply by virtue of their larger acreage.

In the case of giant river prawns, data suggest that extensive farming systems with fish and rice may be more resilient to external shocks such as feed price hikes, disease outbreaks and increases in fuel costs. The annual unit net income of such farms was on average, US$5.7/m², 19 percent higher than the unit income from semi-intensive farms, while that from prawns and fish was similar (Figure 19). The switch by semi-intensive farmers from rice to prawns drastically reduced their income from rice by 58 percent and reduced the overall unit income by about US$1/m² (Figure 19).

FIGURE 19
Income of giant river prawn farmers practising varying levels of intensive farming in Bangladesh



	Total net income	Prawn - total gross income	Fish - total gross income	Rice - total gross income
Extensive (190 m²)	5.7	7.5	2.9	3.1
Improved extensive (280 m²)	5.2	7.4	3.0	2.2
Semi-intensive (450 m²)	4.8	7.2	2.7	1.3

Annual return on income (US$/m²)

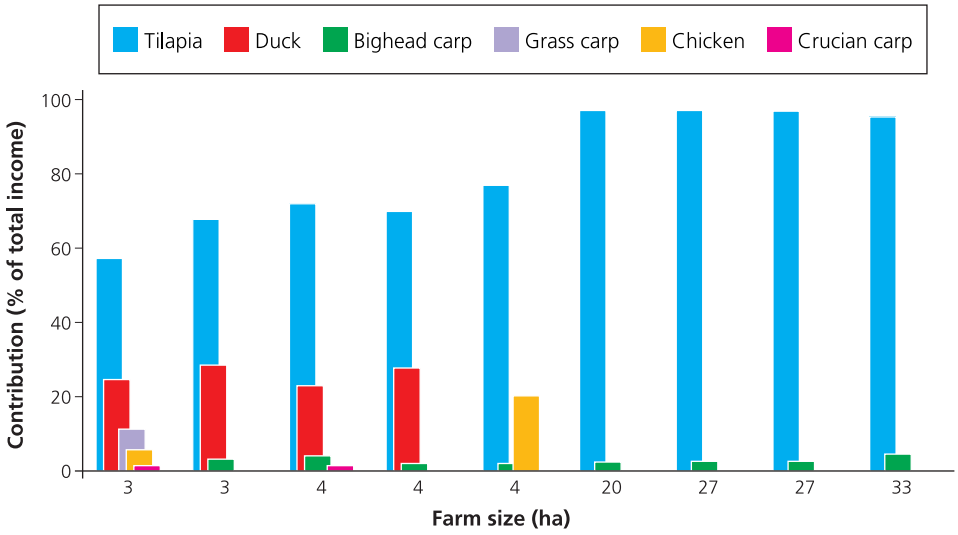
Source: Adapted from Ahmed (2013).

Note: Pond size (in square meters) is given in parentheses.

A similar trend is seen in China. Smaller fish farms diversify their farming activities through horizontal integration with poultry. These practices display a greater resilience compared with monoculture through spreading risk and improving cash flow. About 25–30 percent of income in these farms is derived from either ducks or chickens (Figure 20). Similar to Bangladesh, a few anomalies are seen; the unit return from the larger monoculture farms was similar to or lower than that of small, horizontally integrated farms, with no clear evidence for efficiency gains from scale. However, overall, greater income returns were achieved owing to larger farm size (see Figure 17).

In India, there is also a trend to intensify farming practices to improve the productivity and production of black tiger shrimp (Ramaswamy, Mohan and Metian, 2013). As elsewhere, the merits of such an approach will be determined by the degree of return on investment, in terms of both time and money. Black tiger shrimp farming in India is practised at three levels, with varying degrees of increasing inputs: extensive, improved extensive and semi-intensive (Table 9). Key features of intensification in black tiger shrimp farming in India include increase in stocking density from 4 to 8–20 PL/m², use of commercial feeds, water exchange and aeration (Table 9). Although these inputs increased production, the net return from such interventions in semi-intensive shrimp culture resulted in less than half the net unit return compared with improved extensive management.

FIGURE 20
Relationship between farm size and diversification of farming activities in China



Source: Adapted from Liu *et al*. (2013).

TABLE 9
Inputs, yield and returns with intensification of black tiger shrimp farming in India

	Extensive	Improved extensive	Semi-intensive
Pond size (ha)	0.5–2.0	0.5–1.5	0.3–1.0
Water exchange (%/day)	–	0–10	5.0–20.0
Stocking density (PL/m^2)	<4	4–8	8–20
Feed	SF/FMF	SF	MPF
Aeration	none	partial aeration	continuous aeration
eFCR	1.27	1.31	1.38
Annual yield (tonnes/ha)	0.2–0.5	0.8–1.7	1.8–3.3
Net income (INR/kg shrimp)	59 (US$1.3)	50 (US$1.1)	24 (US$0.5)

Notes: SF = supplementary feed; FMF = farm-made feed; MPF = manufactured pelleted feed; eFCR= economic feed conversion ratio; US$1.0 = Indian rupees (INR) 46.4 using 2010 exchange rate.
Source: Adapted from Ramaswamy, Mohan and Metian (2013).

Overall, all these case studies suggest that there appears to be no automatic benefit of scale with regard to productivity, the higher incomes from intensive farms being mainly derived by virtue of their larger farm sizes.

4. OPTIONS TO IMPROVE PRODUCTIVITY

4.1 Approaches for improvements

The main purpose of intensification is to increase production volume and efficiency while reducing costs. Such increases are achieved through a spectrum of physical interventions and feed management strategies. Fish ponds continue to be a choice of production method. This synthesis acknowledges that farm output is the summation of all interrelated interventions but elaborates on the performance of feed and feed management practices as measured by production volumes and efficiencies.

Although the case studies illustrate that higher productivity is not automatically achieved with increasing inputs, various feed and feed management options are proposed in these case studies and these are tabulated in Table 10.

TABLE 10
Focus areas advocated for improving aquafeed performance and feed management and reducing feed costs

Diet performance	Feed management
• Promote nutritionally balanced feeds	• Maintain appropriate timing of feeding
• Reduce fishmeal content	• Alternate higher and lower protein diets
• Increase digestibility	• Use mixed feeding schedules
• Choose appropriate pellet type	• Delay onset of external feeding
	• Optimise feed administration

Progress on diet performance and feed management is discussed in detail in the individual case studies presented on the CD–ROM accompanying this publication (Ahmed, 2013; Awity, 2013; Bhujel, 2013; El-Sayed, 2013; Hung and Quy, 2013; Liu *et al.*, 2013; Nguyen, 2013; Ramaswamy, Mohan and Metian, 2013; Romana-Eguia, Laron and Catacutan, 2013; Sarder, 2013) and in Ramakrishna, Shipton and Hasan (2013). For this synthesis, case study data are evaluated to understand which interventions are increasingly deployed and having an impact on increased farm outputs.

4.2 Interpretation and evaluation of productivity

Given that aquafeeds account for up to 80 percent of production costs, their use, together with other interrelated synergistic farm management practices and interventions, has to translate into increased production while reducing production costs. The principal indicator used in aquaculture to evaluate feed performance is the economic food conversion ratio (eFCR), and this is used here to compare the outcomes of feed and feed management practices in selected countries using varying levels of feed inputs. Indeed, some salmon companies in Scotland, the United Kingdom of Great Britain and Northern Ireland, use eFCR as an incentive indicator for employee bonus (K.J. Rana, personal communication, 2011).

When feed inputs are increased, four key synergistic physical management interventions apparent in the case studies must also be recognized for their role in increasing overall output and extracting the best performance from diets:

- aeration of ponds;
- increased stocking density;
- increased water exchange;
- deeper ponds.

Increased aeration of ponds using an array of aeration types is the most common management intervention. In China, Egypt, India and the Philippines, aerators are used in ponds. However, such an intervention, together with increased stocking density can only be justified if reliable and reasonably priced energy supply and infrastructure can be secured to optimize feed utilization.

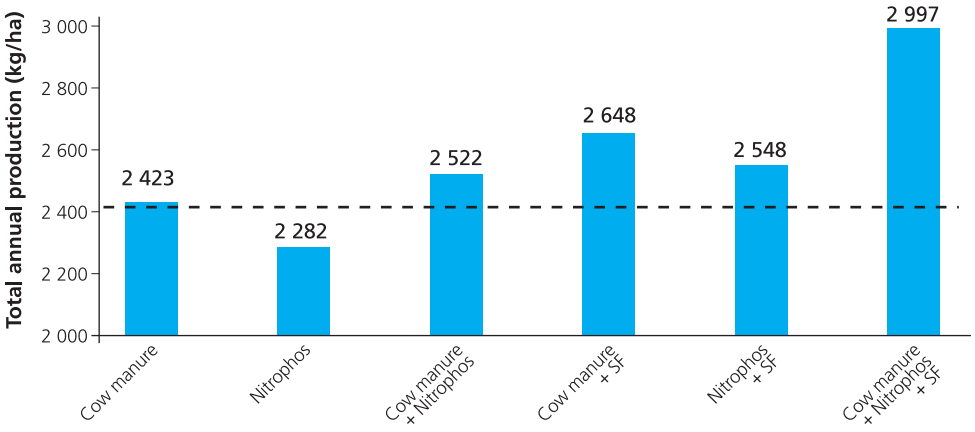
Although production from ponds is often cited as weight per unit area (usually hectares), this assumes that ponds are about the same depth, typically between 0.8–1.0 m. In recent years, farmers in, for example, China and notably in Viet Nam, have increased their tilapia and catfish pond depths to 1.5–2 m and 4–6 m, respectively, as a means of increasing output (Liu *et al.*, 2013; Nguyen, 2013). Accordingly, production from these ponds is typically 8–12 tonnes/ha and 360 tonnes/ha, respectively. Using the averages and adjusting production to a typical pond depth (1 m), such production for tilapia (Liu *et al.*, 2013) and carps

(Ramakrishna, Shipton and Hasan, 2013) is only 4–6 tonnes/ha, which can be easily attained from well-managed fertilized ponds. Careful evaluation of striped catfish farming in Viet Nam also suggests that productivity may not be as high as first envisaged, given the farming practice. Striped catfish ponds in Viet Nam are on average 4.4 m deep and 0.32 ha in size. Given this depth, the very high daily water exchange, typically 30–100 percent/day, and that water volumes in these ponds are typically 4–5 times that of standard ponds, it may be more prudent to interpret production in cubic metres rather than in two dimensions (square metres). For the average striped catfish pond farm yielding 360 tonnes/ha, this translates to only about 8 kg/m^3. This is significantly lower than 100–150 kg/m^3 for the African catfish reared in simple concrete tanks in Nigeria (K.J. Rana, personal communication, 2011) and for cage-farmed tilapia in Egypt (25–30 kg/m^3; El-Sayed, 2013) and the Philippines (4–40 kg/m^3, Romana-Eguia, Laron and Catacutan, 2013).

4.3 Performance of feeds used in aquaculture

This discussion focuses on the eFCR as a measure of feed performance in the selected case studies with reference to international benchmarks and later to the scope for improvement. An evaluation of diet performance based on eFCR as reflected by growth and production in these systems, however, is difficult owing to the confounding effect of unpredictable levels of natural feed in these rearing systems, which can make a significant contribution to overall production (Figure 21). Under comparable polyculture, natural food derived from organic and inorganic fertilizers alone resulted in annual carp production levels of 2.2–2.4 tonnes/ha. When 50 percent of nitrogen (N) for fish in ponds was provided in the form of supplementary feeds, the gross fish production increased by only a further 0.5 tonne/ha (Figure 21). Thus, the value and perceived efficacy of artificial feeds, especially supplementary feeds, will need to be more carefully evaluated. Nevertheless, irrespective of the contribution of natural feeds, given the high proportional production cost of feed incurred by farmers, eFCR is a valid and widely used index to evaluate the merits and justification of artificial feeds. In integrating such data for diet performance, however, due cognizance must be taken of the fact that eFCR is the outcome of the whole farming management system and not diets *per se*.

FIGURE 21
Impact of natural feed derived from a combination of organic and inorganic fertilizers and supplementary feeds on carps reared under similar pond polyculture conditions



Source: Adapted from Abbas *et al*. (2010).

Note: SF = supplementary feed.

The reported eFCRs for tilapias, Indian major carps, catfishes, shrimps and prawns reared on farm-made and commercial feeds from various production systems and intensity of production are given in Tables 11–13. While high water turnover tends to reduce the contribution of natural feeds in cages sited in rivers and lakes (unless highly eutrophic, e.g. Laguna de Bay, the Philippines), natural feeds can and do make a notable contribution in ponds where water exchange is limited. Under cage-farming conditions, natural feeds are generally limited. For cage-farmed tilapia using commercial, mainly extruded feeds, reported eFCR ranged from 1.2:1 to 1.5:1 (Table 11). Data on eFCR for farm-made feeds, which are often presented to fish in powdered form, were scanty but, where available, were notably higher. For striped catfish in Viet Nam and major carps in India, this ranged between 2.9:1 and 2.3:1 to 4.1:1, respectively (Table 12).

TABLE 11
Feed performance (eFCR) for Nile tilapia farmed in countries using various systems

	China	Thailand		Philippines		Egypt		Ghana	
System	**Pond**	**Pond**	**Cage**	**Cage**	**Pond**	**Cage**	**Pond**	**Cage**	**Pond**
Commercial feed	1.69:1[1]		<1.5:1[1]	1.50–1.71:1[1,2]	–	1.00–1.21:1 floating*	1.5–2.5:1[1] sinking	1.2–1.4:1[1] Coppens	1.8– 2.3:1[3]
Farm-made feed	NA	<1[4]	–		XX	Not used		NA	
Fertilizers	XX[5]	XX	–	Not used	XXX	–	X	Not used	xxx

Notes: [1]Intensive. [2]Semi-intensive (farm-made feeds). [3]Extensive (+ limited supplementary feeds). [4]Low FCR is probably due to availability of natural food in the pond. [5]X = not commonly used; XX = commonly used; XXX= frequently used.
*Extruded floating feed.
Source: Liu *et al.* (2013); Bhujel (2013); Romana-Eguia, Laron and Catacutan (2013); El-Sayed (2013); Awity (2013).

TABLE 12
Feed performance (eFCR) for striped catfish and Indian major carps farmed in countries using various culture systems

	Viet Nam	Bangladesh	India
Species	**Striped catfish**	**Indian major carps**	**Indian major carps**
System	Ponds: intensive	Ponds: semi-intensive	Ponds: semi-intensive
Commercial feed	1.6:1	NA	1.8:1–3.4:1
Farm-made feed	2.9:1	1.3:1–2:1	2.3:1–4.1:1
Fertilizers	Not used	XX	XX

Note: NA = data not available; XX = commonly used.

Source: Nguyen (2013); Sarder (2013); Ramakrishna, Shipton and Hasan (2013).

Such relatively high eFCRs (2.1:1–4:1) were also evident for giant river prawns in Bangladesh fed both commercial and farm-made feeds. The performance of marine shrimps reared in fertilized semi-intensive ponds in Viet Nam and India and fed commercial diets, however, was low at 1.0:1–1.4:1 (Table 13).

TABLE 13
Feed performance (eFCR) for shrimps and prawns farmed in countries using various culture systems

	Bangladesh	India	Viet Nam
Species	**Giant river prawns**	**Black tiger shrimp**	**Whiteleg shrimp**
System	Ponds: semi-intensive	Ponds: semi-intensive	Ponds: intensive
Commercial feed	2.30:1	1.27:1–1.38:1	1.00:1–1.20:1
Farm-made feed	2:1–4:1	NA	NA
Fertilizer	XX	XX	XX

Note: NA = data not available; XX = commonly used.
Source: Ahmed (2013); Ramaswamy, Mohan and Metian (2013); Hung and Quy (2013).

4.4 Presentation of nutrients

Although the data are far from complete, the reported eFCRs shown in Table 14 provide an indication of the broad trend. Farm-made feeds were poorer (1.9:1–4.1:1) when compared with manufactured feeds (1:1–2:1). For pelleted feeds either manufactured by local mills or commercial feed companies, diets appeared to yield similar results. Moreover, there were no clear performance differences between sinking and extruded diets or species, and performance was similar between countries (Table 11). Performance of feeds from cage-reared fish (eFCR 1:–1.5:1) was slightly better than that from pond-reared fish (eFCR 1.2:1–2:1) except for pond-reared whiteleg shrimp where eFCR varied between 1.0 and 1.2 (Table 14).

TABLE 14
Economic feed conversion ratios (eFCRs) for feed types used for farming finfish and shrimps in ponds and cages

Feed type	eFCR	Species	Rearing system	Country	Source
Farm-made feed					
Mash	2.3:1–4.1:1	Major carps	Pond	India	Ramakrishna, Shipton and Hasan (2013)
Mash + pellet	1.9:1	Major carps	Pond	India	Ramakrishna, Shipton and Hasan (2013)
Moist pellets	2.9:1	Striped catfish	Pond	Viet Nam	Nguyen (2013)
Manufactured pellets					
Sinking pellets	1.5:1	Nile tilapia	Cage	Egypt	El-Sayed (2013)
Sinking pellets	1.6:1–2.0:1	Nile tilapia	Pond	China	Liu *et al.* (2013)
Sinking pellets	1.3:1–2.1:1	Major carps	Pond	Bangladesh	Sarder (2013)
Extruded pellets	2.0:1	Nile tilapia	Pond	Ghana	Awity (2013)
Extruded pellets	1.6:1	Striped catfish	Pond	Viet Nam	Nguyen (2013)
Extruded pellets	1.5:1–1.7:1	Nile tilapia	Pond	Philippines	Romana-Eguia, Laron and Catacutan (2013)
Extruded pellets	1.2:1–1.4:1	Nile tilapia	Cage	Ghana	Awity (2013)
Extruded pellets	1.0:1–1.2:1	Whiteleg shrimp	Pond	Viet Nam	Hung and Quy (2013)
Extruded feeds	1.2:1–1.5:1	Nile tilapia	Cage	China	Liu *et al.* (2013)
Extruded feeds	1:1	Nile tilapia	Cage	Egypt	El-Sayed (2013)

It should be noted that the outcomes of diet performance were similar, irrespective of differences in feed administration methods and frequency, whether hand fed or

automatically dispensed. Overall, presentation of the nutrient ingredients to fish seems most crucial. Better utilization is achieved through presenting nutrients in a concentrated form, typically as pellets.

4.5 Reduction of protein and fishmeal in diets

Farmers and feed manufacturers alike are attempting to reduce feed cost and secure ingredients to produce cost-effective diets. Several avenues have been explored. In particular, significant effort has been devoted to research into reducing fishmeal for inclusion in diets. This section evaluates data from farm surveys to assess which interventions may have the greatest impact.

A considerable amount of effort continues to be devoted to fishmeal replacements on the grounds of cost and availability (Rana, Siriwardena and Hasan, 2009; Tacon, Hasan and Metian, 2011), and there is a view that protein levels, including fishmeal, in diets are overprescribed. Specifically, the contention is that fish diets contain too much protein, and that protein reduction, which may increase grow-out time, may result in better economic gain (De Silva, 2010). However, as shown in Table 15, the crude protein levels in aquafeeds from across Asia and Africa (see case studies), with a few exceptions (e.g. shrimp, 35–40 percent) are relatively low, typically between 15–30 percent, with fishmeal only constituting up to 5–10 percent of diets (Table 15). In the last 13 years for which data are available (1995–2008), fishmeal inclusion in major fish and shrimp diets declined considerably (FAO, 2012a). Tacon, Hasan and Metian (2011) point to a reduction of fishmeal use at the global level, reporting the decline in fishmeal inclusion levels from 10 to 3 percent, from 10 to 5 precent and from 28 to 20 percent from 1995 to 2008 for fed carps, tilapias and marine shrimps, respectively.

Striped catfish feeds in Viet Nam, for example, which are estimated to be almost 2 million tonnes, only contain 18–20 percent crude protein, and any further reduction is unlikely to affect costs and will increase feed requirements and other variable costs with no likely gain in farm-gate price. Based on the case study data, a daily delay in harvesting due to an extended growth period will require, each day, an additional 6, 0.3 and 0.16 tonnes of feed per hectare for catfish, whiteleg shrimp and Nile tilapia, respectively (Table 16). Moreover, as the key plant protein sources are internationally traded commodities (e.g. soybean meal, wheat and corn), the bulk sourcing of these ingredients is on a par with fishmeal (Rana, Siriwardena and Hasan, 2009). From the perspective of farmers, the merits of advocated protein reduction will therefore have to be considered from a financial rather than a biological perspective. This is especially so as it will, in addition, incur other higher variable costs such as drugs, pumping, labour, which for striped catfish farming adds up to 8 percent of production costs (Nguyen, 2013).

TABLE 15

Crude protein levels in commercial diets reported in case studies for on-growing of various fish and shrimp species

	Species	Crude protein (%)	Fishmeal (%)	References
Ghana	Nile tilapia	30	NA	Awity (2013)
Egypt	Nile tilapia	25	6	El-Sayed (2013)
Thailand	Nile tilapia	16–30	NA	Bhujel (2013)
Viet Nam	Black tiger shrimp	36–42	NA	Hung and Quy (2013)
	Whiteleg shrimp	32–35	NA	
Philippines	Nile tilapia	22–32	NA	Romana-Eguia, Laron and Catacutan (2013)
Viet Nam	Striped catfish	18–20	3–20	Nguyen (2013)
India	Major carps	8–30	3.5	Ramakrishna, Shipton and Hasan (2013)
Bangladesh	Major carps	25–30	5–10	Sarder (2013)
China	Nile tilapia	28–30	NA	Liu *et al.* (2013)

NA = Data not available.
Source: Case study data.

TABLE 16
Implication of delayed harvesting on additional feed requirements

Case study examples	Standing stock at normal harvest (tonnes/ha)	Extra feed (2%/ha)	
		Tonnes/day	Tonnes/week
Striped catfish	300	6	42
Whiteleg shrimp	15	0.3	2.1
Nile tilapia/Indian major carps	8	0.16	1.12

Source: Case study data.

4.6 Least-cost prioritization options to address feed efficiency - where should the focus be?

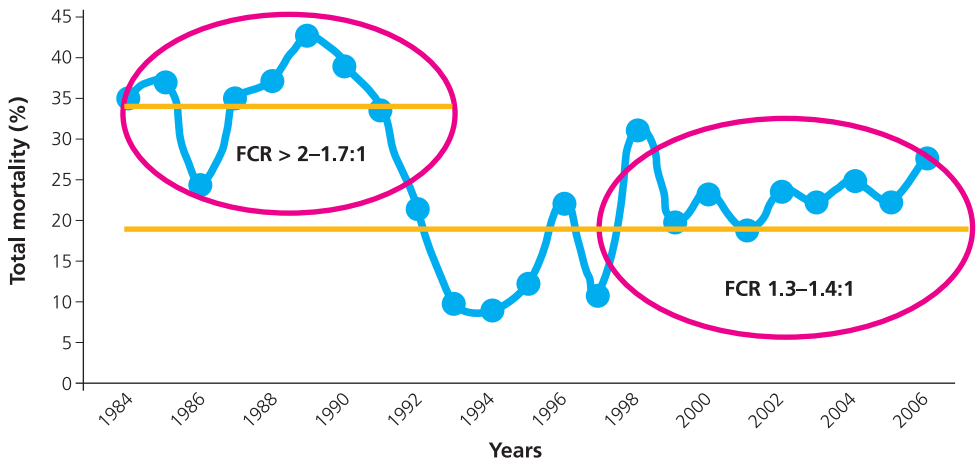
First, it is necessary to revisit the indicator is used for evaluating the farm diet performance (i.e. eFCR), which is a ratio of actual total weight gain and actual total weight feed used (or perhaps more relevantly, the total quantity of feed procured). Hence, without changing feed quality, any improvement in increased harvested tonnage and/or reduced feed usage will improve eFCR. Therefore, it is also necessary to take due cognizance of those factors that could most significantly influence these two variables. Based on the case studies, three main factors are considered here:

- mortality;
- feed presentation;
- storage.

4.6.1 Mortality and eFCR

As indicated in Tables 11–14, the eFCRs in many instances are relatively low and similar to the economic feed conversion efficiencies of the salmonid industry (Kaushik, 2013) and, in many instances, better than those of the seabass and seabream industry in Europe. In Turkey, for example, the FCR is about 1.6:1–2.0:1 for seabream and 1.8:1–2.2:1 for seabass (Okumus, 2005). Nevertheless, lessons may be evident from the historic evolution of diet performance in Europe. Prior to the 1990s, salmon farming in Scotland, the United Kingdom of Great Britain and Northern Ireland, was characterized by relatively high mortalities, with eFCRs in the range of 2:1 and the use of moist diets (Kaushik, 2013). Such performance is similar to that attained

FIGURE 22
Trends in reported Scottish salmon industry mortality pattern *versus* the industry-wide eFCR

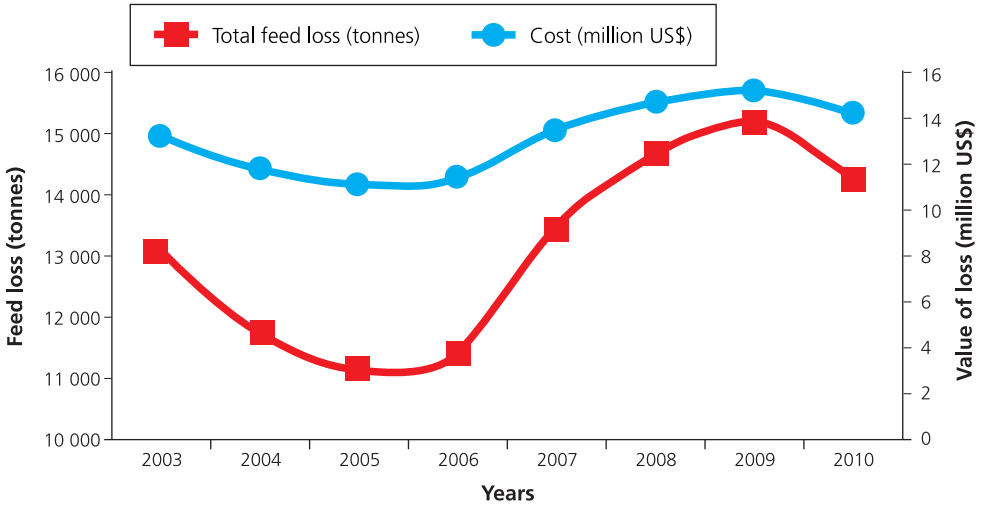


Source: Adapted from www.seeradonline.gov.uk and F. Johnston, FEAP, personal communication (2011).

by farmers using farm-made feeds (Tables 12–14). At the pragmatic farm level, the advent of pelleted feeds in the salmon industry and the improvement in industry-level survival by about 10–15 percent has improved feed performance from 2:1 to 1.3:1–1.4:1 (Figure 22). This was achieved by better accountability for ingredient utilization and improved feed usage through reduced mortality, reflecting higher harvested tonnage.

Taking into account that salmon farms hold two- and three-year-class fish, the feed loss for the industry, which in 2009 produced 144 000 tonnes, can be significant. In 2009, this loss was estimated at 15 000 tonnes valued at US$15 million (Figure 23).

FIGURE 23
Total annual feed loss by, and cost to, the Scottish salmon industry resulting from mortality based on stocked and harvested age classes reported to the Scottish Executive Environment and Rural Affairs Department



Source: Adapted from www.seeradonline.gov.uk

Note: Feed cost = US$1 000/tonne.

The above scenario represents a sector using a single production system, intensive cages. Where national production is significantly higher (e.g. Asia), and where production systems are diverse and operate at varying levels of intensification, total mortality may be significantly higher owing to a number of additional factors. Hence, a consideration of the contributing factors to total mortality may be useful and effective in improving eFCR and hence feed utilization efficiency.

The total mortality during the rearing phase represents all unaccountable fish based on initial stocking density. Losses may be due to a number of factors such as predation, theft, disease, handling and transport losses and escapes (Box 1). Given that the eFCR is a ratio of net weight gain and total feed used (Box 1), it would be prudent for farmers to target their efforts to identify significant contributors to total mortality to improve eFCR, irrespective of the type and quality of on-farm feed used. The Asian and African case studies suggest total mortalities may be significantly higher than in Europe, ranging between 30 and 50 percent during the grow-out phase (Table 17). An appreciation of the contributing factors to total mortality may therefore be useful in improving feed utilization efficiency.

Box 1
Mortality, net weight and eFCR

Total mortality (weight) = Total biomass loss from predation over production cycle + theft + disease + handling + grading + escapes

Total net weight at harvest = harvest weight – stocking biomass (if large fingerlings/yearlings used)

$$\textbf{eFCR} = \frac{\text{Total net weight gain at harvest (kg)}}{\text{Total feed used or procured}}$$

TABLE 17
Mortalities reported during the grow-out phase on farms in various countries

Country	Species	Mortality (%)	Stocking size (g)	Source
Egypt	Nile tilapia	25–35	NA	El Naggar, Ibrahim and Abou Zead (2008)
China	Nile tilapia	Up to 50–60	Up to 50	Liu *et al.* (2013)
Thailand (ponds)	Nile tilapia	40–50	NA	Bhujel (2013)
Thailand (cages)	Nile tilapia	35–40	30–50	Bhujel (2013)
Viet Nam (if harvested at 1.2 kg)	Striped catfish	38–40	50	Nguyen (2013)
Bangladesh	Giant river prawns	30	NA	Ahmed (2013)
Bangladesh	Indian major carps	35	NA	Sarder (2013)
Philippines	Nile tilapia	40	50	Romana-Eguia, Laron and Catacutan (2013)

NA = data not available.

The reasons for such mortalities or why such losses occur during the grow-out phase are unclear from the case studies in this document but they are crucial to understanding and developing strategies for improving on-farm feed utilization efficiencies. In these case studies for finfish, high mortality immediately post-stocking may be relatively rare given that larger fingerlings are stocked. In China, Thailand and Viet Nam, for example, 50 g fingerlings are used (Table 17). In instances where small fry or fingerlings (e.g. 3 cm) are used, predation could be higher. With larger fish, losses from theft and diseases are likely to be greater. In China, farmers have reported up to 30 percent losses due to bacterial diseases, possibly initiated by inadequate water quality management (Liu *et al.*, 2013). Such mortalities are likely to be increasingly prevalent as stocking densities are increased and total biomass increases beyond the carrying capacity of the rearing system. In such cases, relatively larger fish will be lost, reducing the harvestable yield and increasing feed loss and the eFCR of diets used.

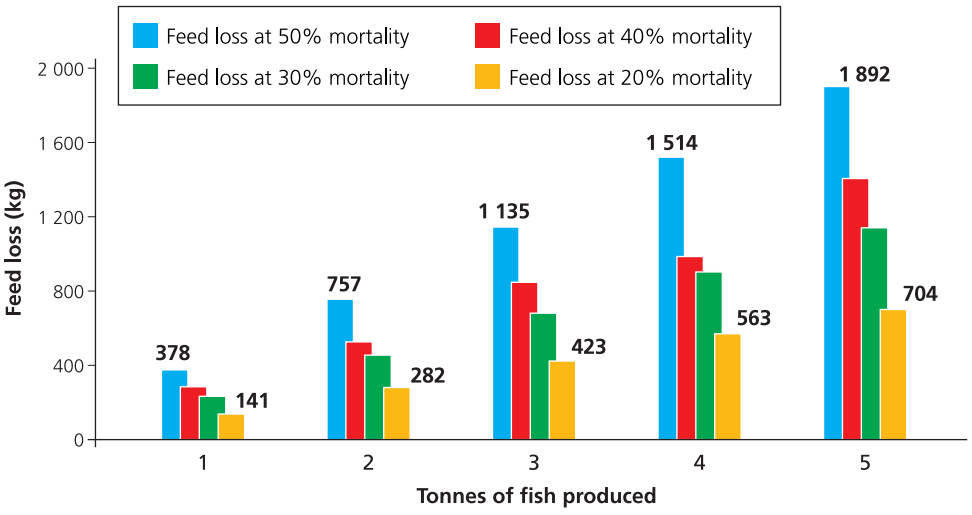
The details on such impacts are limited in the literature and are unavailable in the case studies. However, modelling such losses can shed some insight into their significance. The impact of total mortality on potential farm feed wastage using a typical growth rate (1.9 percent/day) and simulated survival pattern under different production levels (Table 18) is illustrated for tilapia in Figure 24. If the production of one tonne of fish incurs a total loss of 20 percent, then, over a seven month production cycle, 0.14 tonnes of feed would be wasted. Similarly, 5 tonnes of tilapia production would incur 0.7 tonnes of feed loss. At 50 percent mortality, such waste escalates to 0.4 and 1.9 tonnes, respectively. In Bangladesh (Sarder, 2013), the Philippines (Romana-Eguia, Laron and Catacutan, 2013), Egypt (El-Sayed, 2013) and Ghana (Awity, 2013), where feeds prices are reported as US$435, US$500, US$650 and US$1 000/tonne, respectively, farmers producing one tonne of fish and incurring 20 percent total mortality would lose

US$61, US$70, US$91 and US$140/tonne of fish harvested, respectively. At 50 percent mortality, these losses would reach US$170–390/tonne of fish harvested (Table 19).

TABLE 18
Simulated survival pattern for four final mortalities

Month	Final mortality (%) at end of 7 month grow-out phase			
	20	30	40	50
	Simulated survival pattern (%)			
1	100	100	100	100
2	95	90	80	80
3	90	85	75	70
4	90	85	75	65
5	85	80	70	60
6	85	75	65	55
7	80	70	60	50

FIGURE 24
Predicted feed loss under various final total mortality scenarios and production levels of tilapia



Source: This review.

Note: Survival pattern used in model for mortality scenarios given in Table 17.

The later and greater the mortalities occur in the production cycle (i.e. the greater the biomass), the higher the financial losses are. The significance of mortality and its financial impact on economic viability also varies between countries depending on the price of feeds. Irrespective of diet quality, the financial loss in Ghana is 2.3 times greater than in Thailand for the same amount of fish produced (Table19). Therefore, irrespective of diet type and quality, the first priority of farmers to improve eFCR must be to assess and critically reduce mortality to increase tonnage harvested and reduce financial loss.

TABLE 19
Monetary loss for each tonne of tilapia produced under various mortality scenarios

Country	Feed cost (US$/tonne)[1]	Feed loss (US$/tonne of fish produced)			
Total mortality at harvest (%)		20	30	40	50
Thailand	435	61	100	122	170
Philippines	500	70	115	140	195
Egypt	650	91	150	182	254
Ghana	1 000	140	230	280	390
Feed loss (tonnes/tonne fish of harvested		0.14	0.23	0.28	0.39

[1]Feed price based on case study data, feed loss from Figure 24.

4.6.2 Feed presentation

The highest cost component in feed production is the ingredients. Therefore, the key consideration in improving eFCR should be maximization of feed ingredient utilization by the fish. The presentation of ingredients to fish is briefly explored here, based on case study information from the countries.

Feed is presented to fish in ground and powdered form (Sarder, 2013), as dough balls (Sarder, 2013; Ramakrishna, Shipton and Hasan, 2013) and in two pelleted forms, sinking and extruded (Nguyen, 2013). Overall, where feed presentation is powdered or a dough, the eFCR is notably higher than if the ingredients are presented in a pelleted form (Table 12). For this case study, it should be noted that both pelleted and mash diets use similar inclusion levels of key ingredients such as soybean meal and rice bran. The inefficiency of single or multiple ingredient presentation to fish as powdered or mashed diet can be illustrated for Indian major carps in India using the bag–mash feeding method in which mixed ingredients are placed. The eFCRs for mash-fed systems are 2.3:1–4.1:1, whereas those of pelleted feeds are acknowledged as one third that of mashed feeds (Ramakrishna, Shipton and Hasan, 2013). However, data on comparative unit costs of feeds were unavailable. Farmers broadcast or place such feeds in bags in ponds, and the capacity of fish to acquire and utilize these dispersed feed ingredients is low. Thus, it is prudent for farmers to develop simple on-farm pelleting and drying of feeds using the same ingredients to ensure better acquisition of ingredients with reduced effort and wastage. Therefore, the second priority is to encourage farmers to switch from using single-ingredient or moist diets to compressing the same single or mixed ingredients into dry pellets.

Pellet stability

The case studies highlight two key areas for consideration for pelleted feeds: cohesion of major ingredients in pellets; and stability of pellets in water. Both have an impact on wastage and utilization. Poorly compressed and bound pellets can result in unacceptable breakage resulting in “fines” or dust that is unlikely to be consumed by fish and becomes an expensive route to fertilize ponds. Pelleted diets produced by smaller feed factories in China were regarded as of inferior quality (Figure 25). According to Liu *et al.* (2013), ingredients used for diets were not adequately ground and hence pellet integrity was poor, resulting in a high percentage of powdered diet being wasted. Poor pelleting is not just a concern for farm-made feeds. In Malawi, compressed

pellets manufactured by feed mills can also be of suboptimal quality (Figure 26). In some instances this can exceed 15 percent (K.J. Rana, personal communication, 2011), contributing to financial loss and poorer eFCR. This hidden cost can be significant for larger farms, and it varies between countries owing to price differences (Table 20). The cost implication of varying amounts of fines and dust per tonne of fish feed and for a tonne of fish produced using feed with 5 percent fines and dust at various eFCR is presented in Table 21 for various countries. Depending on the eFCR achieved, farmers in Bangladesh will incur losses of between US$19 and US$31 for each tonne of fish produced, whereas in Ghana, where feed price is considerably higher, these losses equate to US$40–58.

TABLE 20
Monetary loss for each tonne of fish and shellfish produced under varying mortality scenarios

Country	Feed price (US$/tonne)[1]	Monetary cost of "fines" (US$) at 80% feed wastage		
Percentage fines		2.5	5	10
Major carps, Bangladesh	390	8	16	31
Nile tilapia, Egypt	425	9	17	34
Major carps, India	450	9	18	36
Nile tilapia, Philippines	600	12	24	48
Nile tilapia, China	560	11	22	45
Black tiger shrimp, India	640	13	26	51
Nile tilapia, Ghana	720	14	29	58

[1]Based on estimates from case studies.

FIGURE 25
Locally pelleted feed in China
[Note the high level of disintegrated pellets and dust]

Source: Liu *et al*. (2013).

FIGURE 26
Pelleted feed produced in Malawi
[Note the high level of dust and crumbled pellets]

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TABLE 21
Financial loss incurred by farmers per tonne of fish and shrimp produced at various eFCR using diets containing 5 percent fines and dust

Country	Financial loss (US$) per tonne fish produced at 5% dust and fines in diets at various eFCRs				
	1.2	1.4	1.6	1.8	2
Bangladesh	19	22	25	28	31
Egypt	20	24	27	31	34
India (fish)	22	25	29	32	36
Philippines	27	31	36	40	45
China	29	34	38	43	48
India (shrimp)	31	36	41	46	51
Ghana	35	40	46	52	58

Related to compression is the binding of ingredients in pellets to optimize their water stability such that fish consume the whole pellets, thus benefiting from a complete diet. The third priority should be to focus on methods to reduce dusts and fines in feeds and optimize the binding properties of pellets to improve pellet hardness and water stability.

4.6.3 Feeding strategy options

In most cases, farmers feed their fish a ration of 2–3 percent of body weight per day, 1–2 times a day. Smaller farmers disperse their feeds by hand (e.g. Ghana, the Philippines and Thailand) or in bags (India), whereas larger farms deploy automated (e.g. China) or demand feeders (e.g. Egypt); however, there appear to be limited gains in reduction in FCR through use of the latter. The priority of farmers is to reduce feed costs, and they have responded to this challenge by adopting various cost-saving strategies in the administration of feeds. These include the use of:

- fertilizers;
- alternate day feeding;
- alternative feeds with low and high-quality diets;
- feeding to satiation.

The most notable and promising approaches seem to be restricted feeding regimes and alternate use of high and low-protein diets.

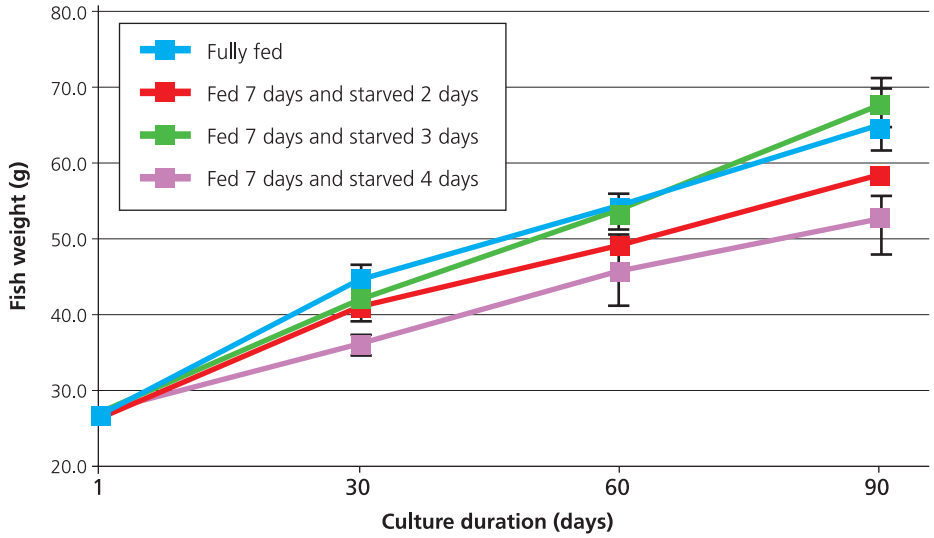
Use of fertilizers

Fertilizers, both organic and inorganic, are extensively used to provide natural food. Poultry and cattle manure is predominantly used at annual rates of up to 13 tonnes/ha (India). In view of projected demands for fish globally and changes in land use patterns, the required tonnage of organic manures to provide the nutrient source for natural foods and fish is unlikely to be available and therefore, reliance on such fertilizers will be increasingly unpredictable. Moreover, some studies have indicated that the cost of macronutrients in dry chicken manure (on the basis of available amount of nutrients per 100 kg of manure and fertilizer) is seven times greater than inorganic urea for N and four times more than triple super phosphate for P (Knud-Hansen, 1998). In addition, the action of inorganic fertilizers is faster than organic manures; they require less labour and have a lower demand on dissolved oxygen. The value of fertilizers in providing micronutrients via natural food, however, may be a useful contribution to reducing on-farm feed costs, and the matter requires further research. A more promising farmer-driven approach is alternate day and diet feeding.

Restricted feeding and alternate feeding regimes with low and high-quality diets

Restricting feeding frequency to once a day was reported to reduce eFCR for striped catfish by 17 percent (Nguyen, 2013) for fish more than 500 g, and further reductions can be achieved by extending this feeding regime over the entire cycle, although this may extend the grow-out period by three weeks (Nguyen, 2013); however, the extra cost for three weeks of rearing is unclear. The growth of fish fed for 7 days and then starved for up to 3 days was not significantly different from that of fish fed daily (fully fed; Figure 27), and reduced eFCR by 18 percent (Nguyen, 2013).

FIGURE 27
Growth of striped catfish fed different restricted feeding regimes

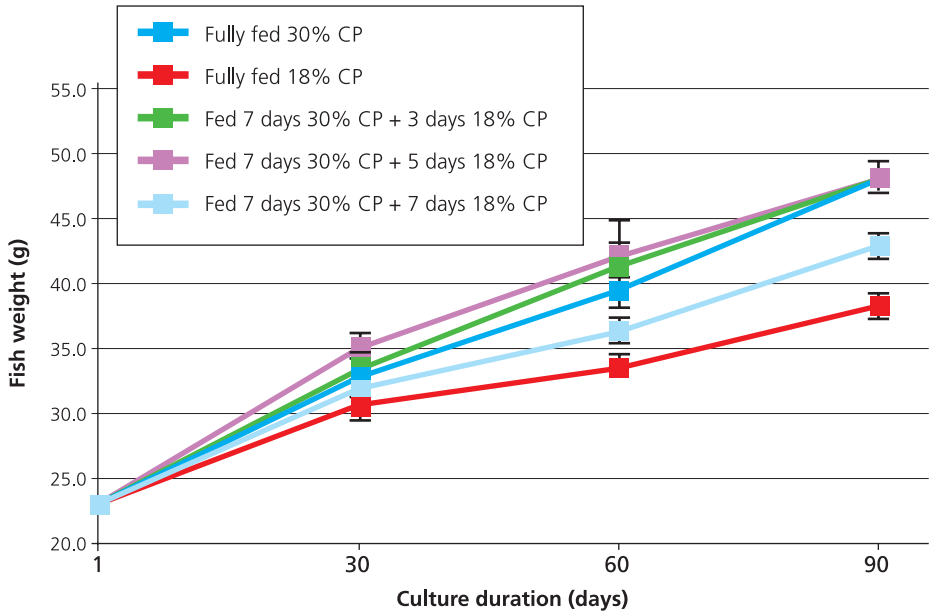


Source: Nguyen (2013).

In the Philippines, alternate feeding has shown promising results, and farmers who have adopted the schemes have noted a positive impact on reducing production costs (Romana-Eguia, Laron and Catacutan, 2013). Alternate feeding with high

and low-protein commercial pellets also appears to be effective in reducing eFCRs. The growth rates of striped catfish fed 30 percent protein pellets for 7 days and then fed on 18 percent protein pellets for the next 3 or 5 days were not significantly different when compared with those fed only 30 percent protein diets all of the time (Figure 28), although it should be noted that these and other studies were conducted on fingerlings.

FIGURE 28
Growth of striped catfish fingerlings fed different alternate feeding regimes of high- and low-protein commercial diets



Source: Nguyen (2013).

Note: CP = crude protein.

Mixed feeding schedules using high and low-protein diets were demonstrated to be useful for many other cultured species, such as common carp (*Cyprinus carpio*) (Srikanth *et al.*, 1989); catla (*Catla catla*), rohu (*Labeo rohita*) and common carp (Nandeesha, De Silva and Krishna Murthy, 1993; Nandeesha, Gagadhara and Manissery, 2002); Nile tilapia (Santiago and Laron, 2002; Patel and Yakupitiyage, 2003); striped snakehead (*Channa striata*) (Hashim, 1994); and tilapia in on-farm trials (Bolivar, Jimenez and Brown, 2006). These studies report better FCRs and suggest significant savings on feed costs. The fourth priority should therefore be for farmers to reduce the extent to which higher protein diets are used.

4.6.4 Feed transport, storage and handling

The final value of feeds to farmers is a summation of all the stages in the production and value chain for fish diets. The transport and storage conditions of diet ingredients and post-manufacture handling and storage conditions of feeds are as important as the nutritional quality of the diet. Inadequate attention to pre- and post-manufacture phases can significantly reduce the economic benefits of any commercial or on-farm feed to the farmer. High humidly (up to 90 percent), high ambient temperatures (up to 50 °C), and improper storage and handling are key factors affecting the end-use quality of feeds and are therefore of particular, although not exclusive, importance in non-temperate countries. Such conditions may result in fungal contamination of both feed ingredients and feeds, reduce nutritional value of ingredients, especially micronutrients, and increase the amount of dust and fines in bagged feed and losses due to pests.

Transport

Imported commercial diets (i.e. Ghana and Nigeria) are particularly vulnerable to spoilage as they have to be shipped by sea freight adding up to 25–45 days to delivery times (from Northern Europe to West Africa) to farms with uncertainty concerning the date of manufacture and transit storage conditions. Bagged diets are often packed in closed metal containers without any climate control, adding to potential diet deterioration caused by high temperatures and humidity build-up. Moreover, in Ghana, feeds are transported in metallic containers on vehicles from the ports to central warehouses in Accra (Awity, 2013) and subjected to higher ambient temperatures and humidity.

Transport of feeds or feed ingredients to farms in open trucks or on motorbikes and bicycles also increases transport times, often compounded by poor road conditions, causing bags to bounce, increasing friction between pellets and hence fines in bags.

Storage conditions and handling

Three key considerations are relevant to optimize feed usage: the control of pests such as rodents, temperature, and humidity; these are of concern in most developing countries. In the central warehouses of large importers in Ghana feeds were stored on pallets above ground level and crevices around buildings were plugged to keep out rodents. Small farmers, however, are unable to invest in dedicated storage facilities; feed storage is poor and simple good practices are not followed by farmers. In Ghana, farmers stacked feed directly on the floor during storage. At farms of this type that were visited, gnawed bags with feed spillage and escaping mice were evident. The store rooms at most of the farms visited were not designed to prevent the entry of rodents. One farmer stored feed in the open covered with a tarpaulin at night to keep off the rain (Awity, 2013).

Although private feed mills in Egypt have excellent handling, storage and transportation facilities, complying with the Code of Practice for Good Animal Feeding (FAO, 1998), this is not universal. In Egypt, handling of tilapia feed and storage facilities are regarded as the most serious problem facing the Egyptian aquafeed industry (El-Sayed, 2013). Feed stores at many feed mills have inadequate basic storage and handling standards. Ingredients are piled outdoors on the ground and exposed to direct sunlight, heat, moisture, and other weather conditions (Figure 29).

FIGURE 29
An example of poor feed ingredient storage in the open in Egypt

Source: El-Sayed (2013).

Pellets with high stability have good handling characteristics. If feed ingredients for formulated and on-farm feeds are not finely and uniformly ground and the binders used are inadequate their pellet strength and hardness may not be ideal; this increasing the incidence of pellet collapse and feed dust and fines (Figure 26). This can be especially high, resulting from compression and abrasion between pellets following the rough handling of bagged feeds and by people walking on bags. While not feasible for small operations, the use of forklifts and pallets, or hand-trucks and mini-pallets, to handle multiple bags minimizes handling. Larger fish farms with high volumes of fish inventories requiring significant qualities of feeds have the capacity to build dedicated storage facilities, as seen on striped catfish farms in Viet Nam (Figure 30).

FIGURE 30
Examples of feed storage on striped catfish farms in Viet Nam
(Note that the feed bags off floor on pallets and away from walls.)

COURTESY OF FAO/T.P. NGUYEN.

In China, smaller farmer with limited resources also store feed under poor conditions (Figure 31 left). Larger operators procure feed regularly, and this is transported to fish farms by the feed producers. There, it is usually stored on-farm in well-ventilated brick-tile buildings (Figure 31 middle) or in concrete buildings (Figure 31 right). Whilst these feed stores are watertight, the bags are stacked against walls, reducing air circulation and causing damp spots (Figure 31 middle and right). Storing ingredients and feeds on the floor is also common among small farmers in Viet Nam. The majority (>85 percent) of whiteleg shrimp small farmers in Central Viet Nam keep their feed in their houses (Figure 32) where humidity and temperatures are high.

FIGURE 31
Examples of tilapia feed stores in Guangdong and Hainan provinces, China (left: shanty store in Guangdong Province; middle: brick-tile house in Guangdong Province; and right: concrete building in Hainan Province

COURTESY OF FAO/JIASHOU LIU (LEFT); AND LIU ET AL. (2013) (MIDDLE AND RIGHT).

Examples of poor storage practices also include farmers who were observed to store purchased sacked feed along pond dykes in open weather conditions. This is common in Thailand, where farmers keep feed in covered plastic buckets (Figure 33), where temperatures can be very high, causing loss of micronutrients (Bhujel, 2013).

Many smaller farmers with limited financial resources procure feed ingredients in small quantities from local markets and make on-farm feeds on a daily or weekly basis, thus minimizing on-site storage and reducing the risk of ingredient and feed spoilage.

FIGURE 32
A typical in-house feed store in whiteleg shrimp farm, central Viet Nam

Source: Hung and Quy (2013).

FIGURE 33
Feed stored in plastic bucket at pond side in hot and humid conditions, Thailand

Source: Bhujel (2013).

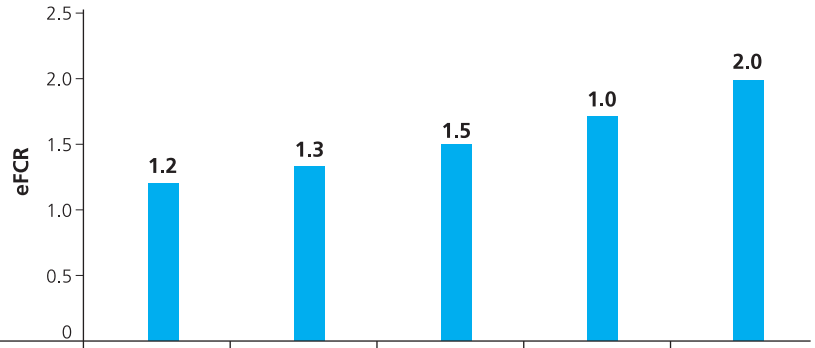
5. CONCLUSIONS – FOCUS FOR IMPROVING FEED EFFICIENCIES.

In this assessment, the eFCR has been used as a primary indicator for on-farm feed utilization efficiency. Where available, data in case studies where commercial feeds are used suggest that eFCR is comparable with developed-country benchmarks for species such as Atlantic salmon in Europe (cf. Table 14 versus Figure 22).

As indicated in Table 10, several options are advocated to improve feed efficiencies. However, farmers will have to prioritize options to focus on those providing the best

gains. In this synthesis, it has been shown that total fish mortality has a significant bearing on feed wastage. At just 20 percent total mortality, about 140 kg of feed is wasted (Figure 24) for every tonne of tilapia produced. The impact of such losses on eFCRs is illustrated in Figure 34. In an ideal scenario of no mortality, and using better management practices (BMPs), one can assume an eFCR of 1.2:1 (or the requirement of 1.2 tonnes of feed to produce one tonne of fish). Using the same feed quantity and a mortality rate of 20 percent will increase the eFCR to 1.5:1, and similarly at 40 percent mortality the eFCR jumps to 2:1, irrespective of diet quality. This highlights the paramount importance of mortality reduction strategies as a primary measure to improve feed utilization efficiencies. In addition, for tilapia, 20 percent mortality also incurs a financial loss of feed to the value of US$60–140/tonne of fish produced (Table 19).

FIGURE 34
Hypothetical changes in eFCR with increasing mortality



Biomas at harvest (kg)	1 000	900	800	700	600
Mortality (%)	0	10	20	30	40

Source: This review.

Note: 1 000 kg fish at 0% mortality at ideal eFCR of 1.2:1 (1 200 kg feed); if same feed volume used with 10% mortality, eFCR increases to 1.3:1 and to 2.0:1 at 40% mortality.

Concentrating feed ingredients into compressed pellets has been equally important in reducing improving) eFCR from 3:1 – 4:1 to 2:1 – 3:1. Pellet quality is also crucial in maximizing the value of diets. Poor pelleting results in dusts and fines and, at just 5 percent, will cost farmers US$19–38/tonne fish produced at an eFCR of 1.2:1. In countries where feed prices are higher and where eFCRs are poorer, these losses will be greater (Table 21).

Considering the factors of mortality, dust in feed, and pellet stability alone, farmers may lose between US$79 and US$178/tonne of fish produced, which highlights where farmers should focus their efforts.

Alternate feeding strategies with high- and low-protein commercial pellets have also proved to be effective in reducing eFCR, with a possible role for fertilizers in fulfilling micronutrient needs of fish. The data in the case studies provide no clear evidence for choosing the more expensive extruded feed over sinking pellets, and it would seem likely that any differences are probably due to the water stability of sinking pellets rather than to any difference in nutritional quality.

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SECTION B
CASE STUDIES

On-farm feed management practices for Nile tilapia *(Oreochromis niloticus)* in southern China

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ABSTRACT

China is the largest tilapia producer in the world. The majority of production is located along the southeastern coast, including the provinces of Guangdong, Guangxi, Hainan and Fujian. In 2010, production from these four provinces was 1 198 000 metric tonnes, representing 90 percent of national production. Although an exotic species in China, Tilapia represents the sixth largest production sub-sector after silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*), grass carp (*Ctenopharyngodon idella*), common carp (*Cyprinus carpio*), and crucian carp (*Carassius auratus*). Nile tilapia (*Oreochromis niloticus*) is the most popular species used for aquaculture in the country. This paper reviews on-farm feeds and feed management practices in tilapia aquaculture in Guangdong and Hainan provinces. The review describes on-farm feeding and feed management practices in different tilapia farming systems, and assesses the economic viability of these operations. Particular attention is given to the current status of feeds and feed management practices. Practical measures to improve the efficiency of feed resources are recommended.

1. INTRODUCTION

1.1 Brief introduction to aquaculture in China

Aquaculture has been practiced in China for over 3 000 years, and the country is currently the world leader in aquaculture production. In 2010, Chinese production reached 36.7 million tonnes, representing 61.4 percent of global aquaculture production (FAO, 2012). Currently, more than one-third of animal protein in the diet of the Chinese people is sourced from fish and other aquaculture products, and the sector has become an important industry in terms of maintaining food security through the provision of income and employment.

Carps, especially the domestic silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis)* and grass carp (*Ctenopharyngodon idella*) are the main species that are cultured in ponds. The diversification of culture species is one of the stated goals of aquaculture development in China (Liu and Li, 2010). The production of non-indigenous (exotic) species increased from 780 000 tonnes in 1998 to 2.5 million tonnes in 2006, representing 5.9 and 11.7 percent of the total inland aquaculture

production in China, respectively (Liu and Li, 2010). Some exotic species have come to play an important role in both aquaculture production and in the economy. Of these, tilapia is the most important exotic species currently cultured in China.

1.2 Overview of tilapia culture

Tilapia are arguably ideal candidates for aquaculture because of their tolerance to wide pH fluctuations, high ammonia and nitrite levels and low dissolved oxygen levels (Ardjosoediro and Ramnarine, 2002). Some species can even be cultured at high salinities (Costa-Pierce and Rakocy, 2000), and they are resistant to many fish diseases and parasites (Costa-Pierce and Rakocy, 2000). In addition, tilapia are fast growing and omnivorous, with an ability to utilize a wide range of feed ingredients such as detritus, blue green or green algae, diatoms, macrophytes and bacteria (Bhujel *et al.*, 2001; Gonzales and Brown, 2006). Currently, tilapia culture is one of the fastest growing forms of aquaculture worldwide, with more than 3 497 390 tonnes produced in 2010 (FAO, 2013). Of the tilapia group, the most popular culture species is the Nile tilapia (*Oreochromis niloticus*), accounting for 73 percent of the total production of tilapia in 2010, with China contributing 39 percent of the global production of Nile tilapia (FAO, 2013). The species has been introduced widely around the world, and it is being cultured in at least 57 tropical and subtropical countries (Pullin *et al.*, 1997). In recent years, the volume of world tilapia production has increased significantly. This increase in production is primarily attributed to aquaculture production in Asia, and especially in China (TBCAPMPA, 2009).

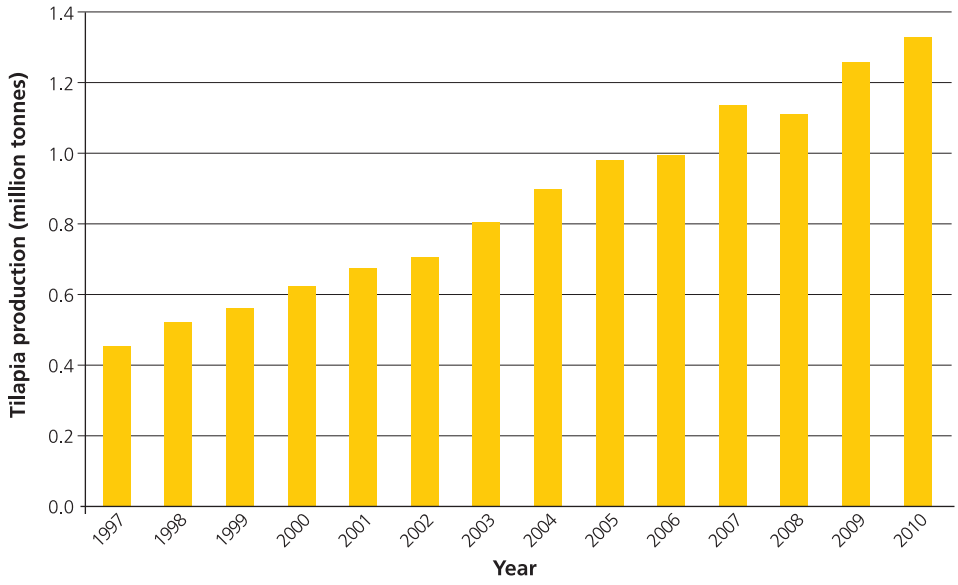
1.3 Tilapia aquaculture in China

Tilapia were first introduced into the country in the 1950s, and are now some of the most successful exotic species cultured in the country (Liu and Li, 2010). Initially the sector developed very slowly. This was attributed to a number of technical issues including the development of breeding and husbandry protocols, the adaption of the farming technologies to the local conditions, and marketing. Initially, the culture techniques that were used for tilapia were the similar to those applied to the Asian carps and other common carp species; and, prior to the 1970s and the introduction of commercial formulated feeds for tilapia, production was based on extensive polyculture systems. Since tilapia have different biological characteristics to the Asian carps, the culture techniques adopted for tilapia aquaculture need to be different. To date, more than eight species of tilapia have been introduced into China; of these, Nile tilapia was found to be the most suitable in terms of cost effective production (Li *et al.*, 2007).

In 1995, the total production of tilapia in China was 32 000 tonnes (He *et al.*, 2009). Over the past thirteen years, national tilapia aquaculture production has increased at an average annual growth rate of 14.6 percent (FBMA, 1998–2011). In 1997, aquaculture production of tilapia was 480 000 tonnes. By 2010, it had grown to 1.33 million tonnes (Figure 1). At a global level, China is now the major producer nation (Lei *et al.*, 2009; FAO, 2013). It is anticipated that in the short term, Chinese production will continue to increase. The anticipated increase is attributed to a favourable market prognosis (Costa-Pierce and Rakocy, 2000), and the low production costs in China (Chen, 2006). In addition, the value and production chains are now well established and the sector enjoys strong governmental support – particularly in Guangdong, Hainan, Guangxi and Fujian provinces. In recent years culture technologies have also greatly improved in China.

Notably, the development of over-wintering technologies using warm spring waters in northern China has enabled production to move further north, to Beijing and Xinjiang. Furthermore, farmers are increasingly recognizing the importance of fish health, product quality and the problems associated with the use of unauthorized therapeutants.

FIGURE 1
Tilapia production in China from 1997–2010



Source: FBMA (1998–2011).

1.4 Regional distribution of tilapia production

Although tilapia are cultured throughout the country, the majority of the production capacity is based in the southern Chinese provinces of Guangdong, Hainan, Guangxi and Fujian, where optimum culture conditions prevail. In 2010, Guangdong produced 624 000 tonnes of tilapia, Hainan produced 251 000 tonnes, Guangxi produced 214 000 tonnes, and Fujian produced 109 000 tonnes (Table 1). The share of tilapia production from these four major producer provinces accounted for 90 percent of the national production in that year, which totalled 1 330 000 tonnes (FBMA, 2011) (Figure 2). In recent years, the growth in production capacity has been substantial. For example, in Yunnan province production increased by 25.5 percent between 2009 and 2010 (Table 1).

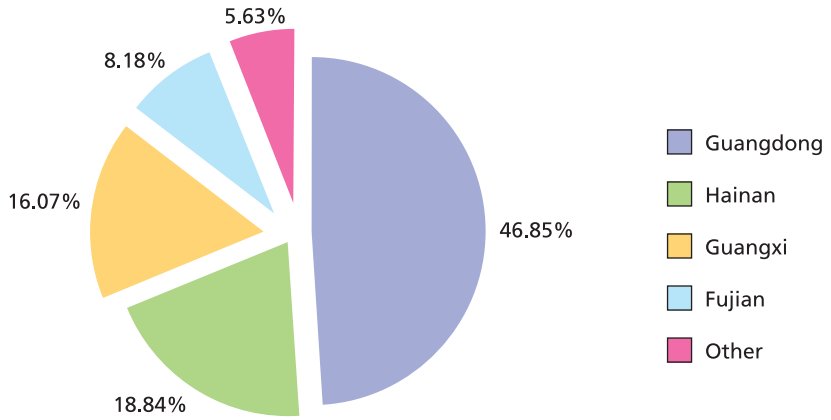
TABLE 1
Yield of tilapia in main tilapia aquaculture provinces in China

Province	2010 (thousand tonnes)	2009 (thousand tonnes)	Increase (thousand tonnes)	% increase
Guangdong	624	584	40	6.9
Hainan	251	246	5	2.0
Guangxi	214	193	21	10.9
Fujian	109	108	1	0.9
Yunnan	59	47	12	25.5

Source: FBMA (2010–11).

China is the largest consumer of tilapia products in the world. In 2006, 66.2 percent of the national production was sold in the domestic market, with the remaining 33.8 percent (375 000 metric tonnes; US$368 million) being exported (Yang, 2008).

FIGURE 2
Main producers of tilapia in China in 2010



Source: FBMA (2010–2011).

1.5 Production systems

1.5.1 Broodstock management

The size of broodstock ponds ranges between 1 to 3 mu[1] (667 to 2 000 m²) with water depths ranging between 1.5 to 2 metres (Yang, 2006a). Prior to stocking, ponds are disinfected using quick lime at a rate of 100 to 150 kg/mu (1.5 to 2.25 tonnes per ha), and then filled with water from rivers, lakes or underground water sources. Water temperatures should be over 18 °C. The ponds are fertilized with fermented husbandry wastes or fermented organic fertilizers, such as grass or vegetables, at a rate of 1 500 to 2 250 kg/ha. One week after fertilization, the broodstock tilapia (250–300 g) are stocked at sex ratios ranging between 3:1 to 5:1 (females: males), and stocking densities of 3 750 to 4 500 per hectare.

In order to induce gonadal development, formulated feeds are fed two or three times a day at a rate of three to five percent of body weight per day. Broodstock ponds should maintain good water quality conditions with sufficient dissolved oxygen. When necessary, new water is added to stimulate spawning. When the water temperature is above 20 °C the broodstock are ready to spawn. Nile tilapia are mouth brooders and the fertilized eggs hatch out in the mouth of the females. When the water temperature is around 25 °C, the fry swim in groups to the water surface. At this time they are ready for harvest. Fry harvesting is normally conducted in the morning or the dawn hours (Huang and Lu, 2005).

1.5.2 Fry production

The ponds used for fry production are 1 to 2 mu (667 to 1 334 m²). One week prior to fry stocking, ponds are filled with clean water to a depth of 50 to 80 cm. In order to promote natural productivity, organic fertilizers are applied at a rate of 400 to 600 kg per mu (6–9 tonnes/ha). A stocking density of 750 000 to 1 500 000 fry/ha is applied. After stocking, the water depth of the pond is increased gradually to1.5 metres. Between 1.5 and 2 kg of soybean milk powder per mu is added to fry ponds as supplemental feeds twice a day, once in the morning and then late in the afternoon. After five to seven days, the fry will have grown to 2 cm. From this moment, rice bran is fed twice a day at a rate of 1.5 to 2.0 kg per 10 000 fry. The feeds should be consumed within two hours of feeding; if they are not, the ration is adjusted to prevent over-feeding. After 10 to 15 days of rearing, the tilapia will have grown to 3 cm and will be transferred to a fingerling rearing facility (Yang, 2006b).

[1] 1 mu = 666.7 square metres.

As an alternative to the conventional fry production systems, GenoMar produce GIFT tilapia seed using broodstock that were originally sourced from the Philippines. Concrete ponds serve as both spawning and rearing ponds. Larval feeds (48 percent protein) are imported from Holland and fed to the larvae six to eight times per day. Feed conversion ratios of 1.2:1 to 1.5:1 are achieved with this feed. Fry and fingerling production is pond based, using locally produced extruded feeds.

1.5.3 Fingerling production

Suitable pond sizes for fingerling production range between 2 to 4 mu (1 334 to 2 667 m^2), and 1.2 to 1.5 metres deep. Rice bran or formulated feeds are used to feed the fingerlings twice a day. Feeds should be consumed within two hours of feeding. After 10 days of rearing, tilapia will have grown to five centimetres, and are ready for grow-out production.

1.5.4 Grow-out production

The grow-out systems that are applied to tilapia culture comprise either ponds (Huang and Lu, 2005) or cages (Yang, 2006c). In pond culture, either monoculture or polyculture systems may be employed. However, tilapia cage culture is only undertaken under monoculture conditions.

Polyculture systems are usually employed by small-scale farmers in China. A typical farm size in Southern China would be between one to two hectares. In these systems, tilapia are normally cultured with the domestic carps, principally silver carp, bighead carp, grass carp, common carp, and mud carp (*Cirrhinus molitorella*). Polyculture systems are used as they result in an increase in the utilization efficiencies of feeds and fertilizers, improved water quality, and make full use of water column and natural food organisms in the ponds (Liu and He, 1992). Normally two methods are adopted for polyculture. The first is to culture tilapia as the primary species, accounting for 70 to 80 percent of pond production. In this case, fingerlings of about five cm are stocked in the summer at a density of 30 000 to 37 500 fish/ha. If fingerlings are to be over-wintered, they are normally stocked at 12–15 cm, and at a lower stocking density of 22 500 to 30 000 fish/ha; since the size of over-wintering fingerlings are larger than the summer stocked fingerlings, the survival rates are also higher. The other species stocked include silver carp (size: 250 g/fish; density: 3 750/ha), bighead carp (250 g; 450 to 600/ha), grass carp (500 g; 750/ha), and common carp (100 to 250 g; 150/ha). Production in these systems varies between 9 000 to 12 000 kg/ha. The second method is to culture domestic carps as the primary species and the tilapia as a supplementary species. In this case, 6 000 to 9 000 over-wintering tilapia fingerlings/ha or 12 000 to 18 000 summer-produced fingerlings/ha are stocked. The rationale for the two stocking rates is outlined above. In these culture systems, total production can reach 12 500 kg/ha, of which tilapia accounts for 2 250 kg/ha.

In China, tilapia polyculture systems are normally integrated with other animal husbandry systems. Integrated fish farming is a traditional farming system with a long history in China (Hu and Liu, 2000), and it is widely considered as a model for utilizing waste products, saving energy, and optimizing the use of local resources in an environmentally sustainable manner (Wan and Wan, 2002). Typically, investment costs are low and as the economic returns are good, the practice is widely adopted by small farmers in areas such as the Pearl Delta Area in southern China. In the developed areas of China, labour and pond rentals are high, and it is necessary to integrate the farming systems to maximize economic returns. Normally, these systems are based on integrating fish farming activities with the rearing of ducks, chickens or pigs. With respect to the aquaculture component, the culture methods that are used are similar to those applied to the polyculture systems. However, the integrated systems provide animal faeces, as well as grasses planted on pond dykes to be used as fertilizers or feeds (Zhao and Ye, 2001).

Tilapia monoculture is the system practiced by large-scale fish farmers. The production from these farms range from hundreds to thousands of tonnes per annum. In contrast to the polyculture systems, the monoculture systems require higher investment costs but result in higher production and economic returns. The size at first stocking is between 3–5 cm (summer stocking) or 8–12 cm for over-wintering fingerlings. Stocking densities between 45 000 and 60 000/ha are used for summer stocking. In contrast, when over-wintered fingerlings are stocked, the stocking density is reduced to 37 500/ha. Grow-out periods range between five to seven months, at which point some of the fish will have grown to >500 g. Typically, productivity ranges between 8 000 and 12 000 kg/ha; however, under optimal conditions, production rates of over 15 000 kg/ha can be achieved. Monoculture is more common in Northern China, where the climate is cooler. Tilapia farming in the North is normally located in areas where there is access to cheap warmwater sources, for example hot spring waters or the cooling waters of power stations. As these systems typically use tanks with high water flow rates, stocking densities can be several times those used in ponds.

Ponds are fertilized using manures, husbandry wastes and fermented silages. Fertilization rates vary between 1 500 to 3 000 kg/ha and depend on the type of fertilizer applied. To reduce costs, the fertilizers normally originate from plants or the faeces of livestock reared on or near the pond dykes. A number of feed sources are available for grow-out. These include trash fish, rice bran, wheat bran, soybean cake, residues from soybean curd production, peanut cake, rapeseed cake, lees (dead or residual yeast), silkworm pupae, duckweed and insects. With respect to maintaining water quality, basic chemical parameters, such as water temperature, pH, dissolved oxygen and transparency are recorded daily. Fertilizers are applied on an *ad hoc* basis to maintain the natural productivity of the system. During the summer months, there is an increase in pond water temperatures, and fresh water is added such that 20 to 30 percent of the pond water is replaced every week. Currently, pond discharge waters are rarely monitored. Disease can be a major production constraint, and thus the use of prophylactic treatments to prevent disease outbreaks is commonplace. In this regard, fingerlings are treated prior to stocking with five percent salt water, or a potassium permanganate solution at a concentration of 0.1 milligram per litre, for 10 to 15 minutes. Ponds are disinfected with quick lime at an application rate of 45 to 75 kg/ha for three to five days, and at monthly intervals. This also enables the pH of the water to be optimized. To maintain dissolved oxygen levels, aerators are used at dawn for 30 to 90 minutes during the main growing season from May to October. During summer, when pond waters become stratified, they may be used in the afternoon for 30 to 120 minutes.

1.5.5 Feeding techniques

Fish are usually fed twice a day and feeding is ceased as the fish reach satiation. Depending upon the weather, farmers may select to feed more than twice a day, or restrict feeding to once a day. It is important to note that feeding frequency has a significant impact on tilapia growth performance. In China, tilapia are commonly fed by automatic feeding machines. Ponds are equipped with one or several feeding machines, according to the size of the pond.

Tilapia cultured in pond systems have access to natural feeds (e.g. protozoans, rotifers, cladocerans, copepods, bacteria, algae and grasses) and therefore, compared to fish that are cultured in systems that have restricted or no access to natural feeds (e.g. tanks and raceways), they require lower levels of supplemental feeding.

In pond polyculture systems, natural feed resources are efficiently utilized by different fish species that feed at different trophic levels (Zweig, 1985; Tacon and De Silva, 1997), making polyculture systems energetically efficient and widely adopted.

Feeds used in Chinese tilapia farming systems comprise three major groups, viz. crude feed ingredients, low protein feeds and high protein feeds. Crude feed ingredients

include low-value agricultural by-products, such as rice bran, and are used in low productivity systems (production >2 500 kg/ha). Low protein feeds usually contain 24 percent crude protein, and include vitamin and mineral supplements. Low protein feeds are used in moderately stocked ponds ranging from 2 500 to 10 000 kg/ha. When outputs are greater than 10 000 kg/ha, high protein feeds are used. The latter usually contain 28 to 32 percent crude protein, and include vitamin and mineral supplements (Lu, 1996).

Aquafeed manufacturing is regulated by the All-China Feed Administration Office, a branch of the Ministry of Agriculture. In 1999, to ensure the development of a responsible aquafeed industry, the State Council enacted the Administration Regulations on Feed and Feed Additives (SCPRC, 1999). Under these regulations, all the feed manufacturers must be certified by the Certification and Accreditation Administration of China (CAAC). Certification is undertaken in accordance to the Feed Product Certification Administration Methods (CAAC, 2003) co-published by the CAAC and the Ministry of Agriculture (MoA) of the People's Republic of China. In order to control feed quality strictly, the Ministry of Agriculture has published more than 100 regulations, standards and rules related to aquafeeds. With respect to tilapia, the national standard Formula Feed for Tilapia was enacted in 2005 (MoA, 2005). This standard provides detailed guidance on issues such as product category, sizes of fish and feeds, processing quality parameters, nutritional composition, labelling, packing, transportation and storage. Currently, there are hundreds of aquafeed manufactures in China and, despite the attempts of central and local governments to regulate them, applying the regulations is often problematic; thus it is often difficult for fish farmers to compare the quality of feeds from different manufacturers.

Tilapia are commonly fed high protein feeds in intensive polyculture and monoculture systems. The total annual amount of feed consumed by tilapia in China is estimated to be about 2 million tonnes (FBMA, 2009). Many of the feed ingredients that are commonly used in aquafeeds, such as cotton seed cake, peanuts, corn, soybean, maize, rice, dried fish, shrimp and fishmeal, have frequently been found to be contaminated by mycotoxins and aflatoxins (Fegan, 2005). Mycotoxins and aflatoxins are a widespread source of contamination of foods and feed worldwide. Aflatoxins exert a substantial impact on fish production, causing disease, high mortality, and a gradual decline in stock quality (Santacroce *et al.*, 2008). Aflatoxin contamination of aquafeeds is widespread, especially in countries with humid tropical climates where substandard methods of feed processing and storage exacerbate the problem (Kong, Lin and Guan, 2013). Though the serious effect of aflatoxins on tilapia has not been observed in China, it is possible that it could become a problem in the future.

2. METHODOLOGY

2.1 Geographic scope of the survey

Guangdong and Hainan provinces were selected for this survey because they represent the top two producer provinces in China (Figure 3). Both Guangdong and Hainan lie in the south of China. Guangdong province is in the sub-tropical monsoon climate zone. Annual temperature fluctuations range between 19 °C and 24 °C. Hainan province is in the

FIGURE 3
Investigation sites in southern China

Source: This review.

tropical monsoon maritime climate zone. Annual temperature fluctuations range between 22.5 ºC to 25.6 ºC. Both provinces are highly suitable for tilapia aquaculture.

In Guangdong province, the main tilapia aquaculture districts are Guangzhou, Zhaoqing, Maomin and Zhanjiang. The area under tilapia production in Guangzhou, Zhaoqing, Maomin and Zhanjiang is about 7 333, 4 000, 14 667 and 6 667 ha, respectively (Lei *et al.*, 2009). In Hainan province, tilapia aquaculture has developed rapidly in recent years, especially in Wenchang. By 2008, the total area under tilapia production in Hainan province was about 30 000 ha (www.cctv.com/program/mrnj/20080426/101765.html). The main tilapia aquaculture districts in Hainan province are Wenchang, Danzhou, Chengmai, Haikou and Qionghai.

A total of nine tilapia farms and one tilapia hatchery were surveyed (Table 2). The chosen production facilities provide a representative sample of the types of tilapia farms currently in operation across Southern China.

TABLE 2
Farm sizes and number of stakeholders interviewed in different categories

Stakeholders	Sample size	Locations	Areas
Hatchery operators	1	Hainan province	Hatchery (20 ha)
Grow-out farmers	9	Guangdong and Hainan provinces	Ranging from 2.67 to 33.3 ha

Source: Field survey (2010).

TABLE 3
Basic information of investigated commercial aquaculture farms

Farm code	Location	Area (ha)*	Pond rent (US$/ha/year)*	Culture system	Years in operation
A	Shaxi Village, Jianggao Township, Guangzhou, Guangdong	2.67	3 308	Integrated polyculture	18
B	Datian Village, Jianggao Township Guangzhou, Guangdong	4.00	2 867	Integrated polyculture	13
C	Bopu Township, Zhanjiang, Guangdong	4.00	2 647	Integrated polyculture	14
D	Bopu Township, Zhanjiang, Guangdong	4.00	2 867	Integrated polyculture	15
E	Bopu Township, Zhanjiang, Guangdong	2.67	2 867	Integrated polyculture	17
F	Sanjiang Farm, Sanjiang Township, Haikou, Hainan	33.33	1 323	Revised monoculture**	12
G	Sanjiang town, Haikou, Hainan	26.67	1 102–1 544	Revised monoculture**	10
H	Huaqiao Farm, Tanniu town, Wenchang, Hainan	26.67	1 320–1 544	Revised monoculture**	20
I	Baofeng Village, Dazhi Township, Wenchang, Hainan	20.00	1 320–1 544	Revised monoculture**	14

*These data were originally expressed as mu – a unit of area used in China. One mu equals 666.7 m^2. Fifteen mu equates to one hectare.

**Revised monoculture refers to tilapia that are cultured as the dominant species. Bighead carp are also stocked into ponds to make use of the natural food organisms.

Source: Field survey (2010).

2.2 Data collection and analysis

The farmer surveys were undertaken from 9 to 21 January 2010. Fish farmers were visited and asked to respond to a predefined questionnaire. Follow up visits were undertaken from 14 to 18 August 2010. These follow-up visits were used as an opportunity to clarify issues and collect additional data.

A total of nine tilapia grow-out farms (Table 3) and one hatchery were included in the survey. Data from the facilities were collected and collated into an MS excel spreadsheet for analysis.

3. RESULTS

All the famers in the survey were tenant fish farmers, and thus rented their production ponds. Farm owners are township governments or state-owned agricultural farms. All the fish farmers in the survey had been in the industry for between 10 to 20 years (Table 3). All the ponds were earthen, with sizes ranging between 0.33 ha to 3.3 ha (Figure 4). Five of the farms that were included in the survey used integrated polyculture systems, and the remaining four used revised monoculture production systems. Revised monoculture refers to tilapia that is cultured as the dominant species with bighead carp being a supplementary species that is stocked to make use of the natural productivity of the ponds. Integrated farming systems are widely adopted in southern China; in these farms pond dykes are planted with terrestrial plants, which are used as fish or livestock feed (Figure 5).

FIGURE 4
Typical earthen pond used for tilapia aquaculture in southern China

COURTESY OF FAO/JIASHOU LIU.

FIGURE 5
Example of the cultivation of terrestrial plants along the pond dykes in Guangdong province, China

COURTESY OF FAO/JIASHOU LIU.

In Guangdong province, pond rentals ranged between 18 000 to 225 000 yuan (US$2 600 and US$3 300) per hectare per year. This rental rate was two to three times that reported by farmers from Hainan province. The pond areas that were rented by family farmers in Guangzhou and Zhanjiang in Guangdong province were smaller than those in Haikou or Wenchang in Hainan province. Typically, in Guangdong province the farms are small and family operated. In contrast farms in Hainan province tend to be larger, and the farmers have to employ farm workers to assist in the operation of the facility (Table 4).

TABLE 4
Number of workers, aerators and automatic feeders equipped at each aquaculture farm

Farm code*	Province	Number of workers	Number of aerators	Number of automatic feeders
A	Guangdong	2	4	3
B	Guangdong	2	6	4
C	Guangdong	2	9	6
D	Guangdong	2	10	6
E	Guangdong	2	6	6
F	Hainan	10	50	50
G	Hainan	6	80	80
H	Hainan	4	60	60
I	Hainan	4	40	50

*The farm code in the table is the same as that is presented in Table 3, and is also used in the following tables.

Source: Field survey (2010).

All the farms were equipped with aerators and automatic feeding machines. Due to the need to supply oxygen to the ponds in a cost effective manner, aerator selection is based on pond depth, surface area, biomass, and the efficiency of the aerators, and their running costs (Table 5). Two types of aerators were reported. Turbine aerators (Figure 6) are both efficient and cost effective, and are the most commonly used in China. They are normally deployed in ponds that are more than 1 metre deep, and have a surface area of more than 0.33 ha. Paddlewheel aerators (Figure 7) are usually used in shallow ponds that have a deep layer of silt. The use of turbine aerators in these ponds would be inappropriate as they would re-suspend the silt, resulting in the deterioration in the water quality.

TABLE 5
Installation of aerators for a 0.67 ha (10 mu) tilapia pond

Category	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Fish production (kg/ha/year)	6 000	7 500	9 000	10 500	12 000	13 500	15 000
Oxygen consumption (kg/hour)	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Number of aerators used (any of the types outlined below)							
1.5 KW turbine	1–2	2	2–3	3	3	3–4	4
3.0 KW turbine	1	1	1	1–2	1–2	2	2
1.5 KW paddlewheel	2	2	3	3	4	4	4–5

Source: Field survey (2010).

In order to increase aerator efficiencies, farmers reported adopting the following measures:

- If a few tilapia are observed rising to the surface to gulp air, aerators are operated from midnight until sunrise. If many tilapia start to rise to the surface, the aerators are started immediately.

- On warm rainy days, aerators are started at 03.00 hours to 05.00 hours in the morning and operated until sunrise. Cloudy and rainy conditions decrease photosynthesis and this can result in the depletion of dissolved oxygen levels in the early morning hours. In super-eutrophic ponds, aerators should be started earlier in the night.
- In the summer, aerators are started at 14.00 hours and run for one to three hours to de-stratify the pond waters.

In recent years, the use of automatic feeders has become widely adopted. The correct siting of these feeders in fish ponds is an important consideration, as it significantly affects their efficiency. Normally, the machines are placed in ponds that are between 0.3 and 0.6 ha and 1.5 to 2.5 m deep. The distance between the machine and the water surface is between 30 and 50 cm, enabling the feeds to be sprayed over a wide distance (Figure 8). A typical automatic feeder would have a storage capacity of approximately 65 kg, a power rating of 120 watts, and a spraying radius of 3 to 20 metres. The maximum feed delivery rate is about 160 kg per hour.

While feeding is normally undertaken twice a day, the automatic feeders have the capacity to feed up to ten rations per day. The pellet size used is dependent on the fish size (Table 6).

FIGURE 6
Turbine aerator in a fish pond in Hainan province, China

COURTESY OF FAO/XIAOWU LI AND YAOHUA WANG.

FIGURE 7
Paddlewheel aerator in a pond in Hainan province, China

COURTESY OF FAO/XIAOWU LI AND YAOHUA WANG.

FIGURE 8
Winter scene showing automatic feeders used by tilapia farmers in Hainan province, China

COURTESY OF FAO/XIAOWU LI AND YAOHUA WANG.

TABLE 6
Tilapia sizes and related pellet sizes used in southern China

Category	Body weight (g)	Pellet size in diameter (mm)
Fry	<0.2	0.3–0.6
	0.2–1.0	0.6–1.0
Fingerlings	1.0–1.5	1.0–1.5
	1.5–10	1.5–2.0
Adult fish	10–50	2.0–3.0
	50–250	3.0–3.5
	>250	4.0–4.5

Source: Xiaowu Li and Yaohua Wang, Institute of Hydrobiology, Chinese Academy of Sciences, Wuhan, China, personal communication, 2010.

3.1 Culture technologies and culture species

As discussed, there are two primary culture techniques that are used in Guangdong and Hainan provinces, *viz.* integrated polyculture systems using tilapia as the primary culture species, in which tilapia production is integrated with grass carp, bighead carp, crucian carp, ducks, chicken or pigs; and the revised monoculture systems that are based solely on tilapia and the use of formulated feeds. In some cases, bighead carp are added to the ponds to make use of the natural productivity and maintain water quality at acceptable levels.

Tilapia, grass carp, bighead carp, crucian carp, ducks, chicken and pigs are cultured throughout the year in both Guangdong and Hainan provinces. Most tilapia farmers stock 3 cm tilapia fingerlings in March, and harvest before November (Table 7). Depending on the size and market conditions during the production cycle, small numbers of tilapia may also be harvested between August to October. Where temperatures permit in Hainan province, some farmers over-winter their stock. In winter, grass carp and bighead carp fingerings (>15 cm length) are stocked into ponds and grown out over a year. Crucian carp fingerlings (10–12 cm length) are generally stocked in winter, however some farmers stock fry in April, and harvest in winter. Ducks, chicken and pigs are cultured throughout the year (Table 7). While the use of organic fertilizers, such as fermented grass is limited (dyke areas cannot support the large scale cultivation of grasses), pond fertilization using duck, chicken or pig faeces is commonplace, and is practiced throughout the year. In summer, small amounts of therapeutants may be applied to control diseases. The stocking rates are summarized in Table 8. Typical stocking rates of fingerlings/ha in polyculture systems are 30 000 tilapia, 3 000 grass carp, 450–700 bighead carp, and 750 crucian carp. Some farmers reported culturing GIFT strains of tilapia, as these reportedly have growth rates between 5 and 30 percent higher than conventional strains of tilapia (Li *et al.*, 1997; Li *et al.*, 1998; Dong *et al.*, 2008).

TABLE 7
Polyculture production cycle

Month	Stocking with type of fish/size				Type of livestock			Type of fertiliser		Application of drugs
	Tilapia	Grass carp	Crucian carp	Bighead carp	Duck	Chicken	Pig	Organic (chicken/duck faeces)	Inorganic	
January		15–25 cm		15–20 cm	x	x	x	x		
February		x		x	x	x	x	x		
March	3 cm	x	10–12 cm	x	x	x	x	x		
April	x	x	x	x	x	x	x	x	x	
May	x	x	x	x	x	x	x	x	x	
June	x	x	x	x	x	x	x	x		x
July	x	x	x	x	x	x	x	x		x
August	x	x	x	x	x	x	x	x		x
September	x	x	x	x	x	x	x	x		x
October	x	x	x	x	x	x	x	x		x
November	Harvest size 0.4–0.6 kg	x	x	x	x	x	x	x		
December		Harvest size 2–4 kg	Harvest size 0.2–0.5 kg	Harvest size 2–4 kg	x	x	x	x		

Source: Field survey (2010).

TABLE 8
Summary of reared species, initial size and amount of farmed species

Species	Initial size	Number (individuals/ha)
Tilapia	1–5 cm	22 500–37 500
Grass carp	100 g/fish	3 000
Crucian carp	50 g/fish	600–750
Bighead carp	100–150 g/fish	450–700
Ducks	Duck layers	450–750
Chicken	Table chicken	300

Source: Field survey (2010).

3.2 Feed selection

With the exception of two farms in Zhanjiang, Guangdong province, all the farms reported using commercially manufactured feeds (Figure 9) for fish and ducks. The two farms that did not use commercial feeds processed their own feeds, according to formulations and using ingredients supplied by a local feed manufacturer. Farmers selected feed manufacturers based on their awareness of the brand, the price and growth performance of the fish, or past experiences of using their feeds. However, though the prices of those feeds that were produced by small factories the quality was unsatisfactory, with pellet sizes being uneven, with many of the pellets being received in a powdered form (Figure 10).

FIGURE 9
Various sizes of pelleted feed used for tilapia, Zhanjiang, Guangdong province, China

COURTESY OF FAO/XIAOWU LI AND YAOHUA WANG.

Farmers who used commercially produced aquafeeds in Guangdong province preferred to use extruded floating feeds; in contrast, farmers in Hainan province used sinking feeds. To reduce feed costs, the use of domestic waste (kitchen scraps) was reported by farmers in Guangzhou, Guangdong province. In Hainan province, some farmers reported that the use of extruded feed caused liver-gallbladder syndrome, and hence they chose to use sinking feeds. While these were the perceptions of some farmers, they could not be validated by the study However, liver-gallbladder syndrome is a common disease that is also found in other cultured fishes, such as grass carp (Shi and Wei, 2010), common carp (Wang, 2009), sturgeons (Zhu, 2008) and channel catfish (*Ictalurus punctatus*) (He, 2006). Liver-gallbladder syndrome manifests as lesions and bleeding of the liver.

A wide variety of ingredients are used in tilapia feeds. These include rice bran, wheat bran, soybean cake, residues from soybean curd production, peanut cake, rapeseed cake,

silkworm pupae, duckweed, and occasionally insects. Some of the main ingredients used for commercial/farm-made feeds are listed in Table 9. The proximate composition of commercially available tilapia aquafeeds is presented in Table 10. It is interesting to note that the protein content in the adult tilapia feeds is higher than that suggested by the national standard (25 percent; MoA, 2005). Feed costs ranged between US$536/tonne and US$589/tonne. Feeds are either purchased with cash or on credit. If commercial feeds are not available for a short period of time, or the price of corn is low, farmers may choose to change feeding regimes, and to feed a combination of different grains for a short period of time.

FIGURE 10
Poor quality feeds produced by small factories, Zhanjiang, Guangdong province, China

COURTESY OF FAO/XIAOWU LI AND YAOHUA WANG.

TABLE 9
Feed ingredients used in tilapia feeds in southern China

Ingredients	Proportion of farmers using this ingredient (%)	Type of feed	Codex number (IFN)
Cottonseed cake (solvent extracted)	10–20	Pellet	5-01-632
Peanut meal (mechanically extracted)	0–5	Pellet	5-03-649
Corn flour	20–50	Pellet; farm-made feed	4-08-024
Soybean meal	20–30	Pellet; farm-made feed	5-04-600
Rice bran	0–20	Pellet; farm-made feed	4-03-928
Dried fish	0–5	Farm-made feed	
Shrimp	0–5	Farm-made feed	5-04-226
Fishmeal	50–100	Pellet	5-01-977

Source: Field survey (2010); IFN = international feed number.

TABLE 10
Proximate composition of industrially manufactured sinking and extruded pellets used in tilapia production

Feed ingredients	Proximate composition (%)		
	Fry	Fingerlings	Adult fish
Crude protein	35–38	28–30	27–29
Crude lipid	8	6	5
Fibre	3	6	6 – 8
Ash	16	14	12

Source: MoA (2005).

3.3 Feed management and feeding practices

Feed management practices are summarized in Table 11. In general, farmers fed their fish once or twice a day, ceasing feeding during inclement weather. The use of automatic feeders was reported on all farms (Figure 11). Typically, feeding was to satiation and undertaken over a 30 to 45 minute period, with the farmers monitoring the feeding activity, and adjusting the rations accordingly. Depending on the growth of the fish and the biomass in the ponds, the automatic feeders were recalibrated every 10 to 15 days.

Feeding rates ranged between 3 and 1.6 percent of body weight per day. Recording feed data varied considerably between the farmers, with some farmers calculating feed conversion ratios (FCR), and determining ration portions according to fish size, mortality, biomass, temperature, and observations of the fish feeding response. In contrast, other farmers fed at a fixed rate of two percent of body weight per day throughout the production cycle, with many failing to adequately record feed data or feed efficiencies.

FIGURE 11
Automatic feeder in action (left) and tilapia response to feeding (right)

COURTESY OF FAO/XIAOWU LI AND YAOHUA WANG.

It was estimated that there are approximately 60 feed manufacturers in Guangdong and Hainan provinces. Most of these are small-scale manufacturers with a production capacity ranging between 100 and 1 000 tonnes per month. They supply feed to the local fish farms. Locally produced extruded fry, fingerling, grower and broodstock feeds are available. The cost of the feeds range between US$380/tonne for a simple sinking pellet, to US$955/tonne for specialized fry feeds (Table 12).

TABLE 11
Summary of feed management practices and farm incomes

Farm Code	Farm size (ha)	Feed category	Feed type	Feeding frequency (times/day)	Feeding rate (% body weight/day)	Feed additives	FCR	Maximum time feed stored (days)	Storage facility	Fertilizer	Number of automatic feeders	Net revenue (US$/year/ha)
A	2.67	Complete	Extruded	2	Not available	Water quality improver	NA[3]	15	Brick-tile house	Chicken and Duck faeces	3	10 234
B	4.00	Complete	Extruded	2	2–2.5	Probiotics	NA	10–20	Simple wooden house	Duck faeces	4	2 895
C	4.00	Complete	Extruded	2	2	Not used	NA	20–30	Concrete house	Duck faeces	6	10 047
D	4.00	Farm-made[1]	Sinking	2	2	Not used	NA	20–30	Brick-tile house	Chicken and pig faeces	6	3 547
E	2.67	Farm-made[1]	Sinking	2	1.8–2	Vitamin mix	NA	15	Brick-tile house	Duck faeces	6	1 418
F	33.33	Complete	Extruded	2	2	Probiotics	1.2–1.5	10–15	Concrete house	Organic fertilizers	50	1 377
G	26.67	Complete	Sinking	2	3, 2, 1.6[2]	Probiotics	1.6	10	Concrete house	Carbamide	80	3 840
H	26.67	Complete	Sinking	2	2	Vitamin and mineral mix	1.6–1.7	20	Brick-tile house	None	60	1 033
I	20.00	Complete	Sinking	2	2	Vitamin and mineral mix	1.6–2.0	20	Brick-tile house	Inorganic fertilizers	50	2 128

[1] Feeds used by farm D and E were farm-made feeds. The feed formula was suggested by a feed factory nutritionist, and the feed ingredients were bought from the feed factory, and processed into pellets.
[2] When fish were very small the feeding rate was about 3 percent body weight per day. The feeding rate decreased slowly as fish grew.
[3] NA = not available.
Source: Field survey (2010).

TABLE 12
Major tilapia feed producers in Guangdong and Hainan provinces

Name of feed brand	Price (US$/tonne)	Type of feed
GenoMar	955	Extruded feed for tilapia fry
Tongwei	485	Extruded feed for fingerlings
	455	Extruded feed for adult tilapia
Haida	470	Extruded feed for fingerlings
	440	Extruded feed for adult tilapia
Zhonglian	500	Extruded feed for broodstock
Raoping	380	Sinking feed

Source: Field survey (2010).

Feed is usually stored in well ventilated brick or concrete feed sheds (Figure 12). Storage periods are relatively short, with the majority of feed being used within 20 days of arrival on the farm (Table 11). Feed spoilage was not considered a problem by the farmers.

FIGURE 12
Tilapia feed storage in Guangdong and Hainan province, China
(left: brick storage cell in Guangdong province; right: concrete storage cell in Hainan province)

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3.4 Fertilizers, disinfectants, feed additives and probiotics

Fertilizers, disinfectants, medicaments, feed additives and probiotics are used by some farmers (Table 13). As farmers in Guangdong province usually rear livestock on their farms and plant grasses on the pond dykes, they use chicken, duck, or pig faeces or grasses as fertilizers in their ponds. In contrast, in Hainan province, livestock farming is not commonplace, and thus inorganic fertilizers are often used to replace the livestock faeces.

Prior to application, green grasses are fermented. Typically, grasses are put into a sheltered corner of the pond where they receive maximum sunlight. The grass is covered with dry faeces and stirred every two or three days to promote fermentation. When the grass stems and leaves have rotted, the manure can be used as a fertilizer. Prior to use, the animal faeces also require fermentation. Faeces are usually fermented in tanks and subsequently transferred into the corner of the pond for use. Application rates of both faeces and plant materials vary between 2 000 to 3 000 kg/ha per production season. Grasses and faeces may also be fermented together, and then applied to the ponds in small quantities. Fertilizer application rates are dependent on water quality and transparency. In Hainan Province, fish farmers use inorganic fertilizers during the early stages of their production cycles.

The inorganic fertilizers include nitrogen, phosphorus and calcium. A typical fertilization regime would comprise a mixture of urea and calcium superphosphate at an application rate of 30 to 50 kg/ha every 10 days for the first one or two months post stocking.

TABLE 13

Fertilizers, isolation/disinfection regimes, disinfects, feed additives, and probiotic use on each of the surveyed farms

Farm code	Fertilizer use	Isolation/Disinfection regime	Disinfectants	Feed additives	Probiotics
A	Chicken and duck faeces	Isolated annually	Not used	Quality improver	Not used
B	Duck faeces	Isolated annually	Not used	Immunostimulants	Not used
C	Duck faeces	Isolated annually	Not used	Not used	Not used
D	Chicken and pig faeces	Disinfected every 1–2 year	Unclear	Not used	Not used
E	Duck faeces	Disinfected every 1–2 year	Tea seed cake	Growth promoter	Not used
F	Organic fertilizers	Disinfected every 1–2 year	Quick lime, chlorine dioxide	Immunostimulants	Photosynthetic bacteria, bacillus subtilis, EM fungi[1]
G	Carbamide	Disinfected annually	Quick lime	Immunostimulants	Bacillus subtilis, EM fungi[1]
H	Not used	Disinfected annually	Quick lime	Vitamin C, etc.	Bacillus subtilis, EM fungi[1]
I	Inorganic fertilizers	Disinfected annually	Quick lime	Vitamin C, etc.	Bacillus subtilis, EM fungi[1]

[1] Ectomycorrhizal fungi.

Source: Field survey (2010).

Prior to stocking, the ponds are disinfected with quicklime at a rate of 1 000–1 500 kg/ha or, alternatively, calcium chloride is applied at a rate of 200 kg/ha. Three days after treatment, fertilizers are applied and the fingerlings are stocked between five to seven days later. Prior to stocking, the fingerlings are normally placed in a bath containing salt water (five percent saline) or potassium permanganate (0.1 mg/l) for 10 to 15 minutes. The treatment is designed to kill bacteria and parasites. During the growing season, quicklime is added to the ponds as a disinfectant at a rate of 45 to 75 kg/ha over three to five day periods. It is also used to maintain optimal pH in the pond water. This process is undertaken on a monthly basis throughout the grow-out period. Prior to the grow-out season, farmers sterilize the pond bottoms by drying the ponds in the winter, and ensuring that they are exposed to a minimum of 15 days of isolation.

Feed additives are widely used by the farmers. These include immunostimulants such as vitamin C, ß-dextran, amino acids, and feed attractants (Table 13). The use of feed additives varied between the famers. Normally, amino acids are added to the diet at a rate of 0.05–0.10 percent of the daily ration. Vitamin mixtures are added at doses of 200 to 300 g per tonne of feed. Combined trace minerals are added at doses of 0.2–0.5 percent of the feed.

The use of probiotics to improve water quality was reported in Hainan province, but not in Guangzhou province. Photosynthetic bacteria, *Bacillus subtilis* and Ectomycorrhizal fungi (EM fungi) were the most commonly used. While all the probiotics were commercially available, many make unsubstantiated claims of efficacy, and the active ingredients are not always listed on the product labels. An example of a probiotic where the active ingredients are listed, which is marketed by the Dabeinong Group Co. Ltd. (http://kh.dbn.cn/) under the trade name 'Lishuisu' – meaning beneficial for water quality (Chinese). The product labelling indicates that it is designed to decompose organic waste, improve water quality, rapidly decrease ammonia nitrogen, nitrite and hydrogen sulphide concentrations, promote natural productivity, prohibit the reproduction of harmful organisms, decrease the amount of therapeutant drugs required, and improve fish quality. The suggested dose is 5 kg/ha and, to be effective it should be applied three times or more. The main components of the product are listed in Table 14. Probiotics are not used in traditional tilapia and Chinese carp pond culture; however the use of probiotics in other production systems is increasing (Dai, 2010).

TABLE 14
Ingredient composition of 'Lishuisu'

Ingredients	Quantity (per 500 g)	Ingredients	Quantity (mg/500 g)
Bacillus subtilis spp.	1 700 billion CFU	Vitamin K	2 200
Saccharomyces spp.	1 200 billion CFU	Vitamin B_1	200
Vitamin A	1 000 000 IU	Vitamin B_2	580
Vitamin D3	150 000 IU	Vitamin B_6	120
Vitamin E	7 000 mg	Vitamin B_{12}	1

Source: http://kh.dbn.cn.

3.5 Fish pathology

The surveyed farmers indicated that disease was a perennial issue, and that disease outbreaks normally occurred between June and August. Farmers usually attribute disease events with poor water quality or poor feed management. On encountering a disease outbreak, most farmers decrease feeding rates or cease feeding. Therapeutants used including florfenicol, and various Chinese medicinal herbs are routinely applied. Florfenicol, an antibiotic that is designed for animal use, is added to the feeds at 0.5 kg/tonne. The fish are medicated for a one week period. Fifty–seven Chinese medicinal herbs, amounting to 32 percent of the fish therapeutants available in China, are used; however most are not formally licensed for use as veterinarian drugs.

3.6 Cost-benefit analysis

A financial analysis of the fish farms surveyed in this study is presented in Table 15. The net profits per hectare per annum in Guangdong province ranged between US$1 418 to US$10 234 (mean: US$5 628). In Hainan, net profits ranged from US$1 033to US$3 840 (mean: US$2 095). Evidently, the mean net profit per hectare of production in Guangdong province was 2.7 times that in Hainan province. The relative production costs of the farm inputs are presented in Table 16. Feed costs ranged between 68 and 84 percent of total production cost, and represented the single greatest production cost. Pond rental costs represented the second largest production cost. In Hainan province pond rental accounted for between 5.7 to 7.8 percent, and in Guangdong province, these costs ranged between 9.8 and 16.2 percent. In Guangdong province, the labour cost was the third largest cost. The proportion of fish seed cost in both provinces was similar, ranging from 2.0 percent to 3.8 percent.

Income derived from each culture species in the polyculture systems is presented in Table 17. There is a difference in those derived from the integrated polyculture system in Guangdong province and the revised monoculture system in Hainan province. In the integrated polyculture system, the income derived from tilapia ranged from 57 to 72 percent, while in the revised monoculture system, it ranged from 95 to 97 percent. In Guangdong province, the income from livestock accounted for 20 to 30 percent of total income. Since pond rentals are higher in Guangdong province, the use of integrated farming systems could compensate for the rental high cost, and still provide adequate economic returns.

TABLE 15

Production costs and income streams of tilapia farms in Guangdong and Hainan Provinces

Farm code	Cost (US$/year)								Total costs (US$/year)	Income (US$/year)		Total income (US$/year)	Net income (US$/farm)	Farm size (ha)	Net earnings (US$/year/ha)
	Pond rental[1]	Labour[2]	Utilities[3]	Feed	Drugs	Feed additives	Pro-biotics	Fish seed		Tilapia	Other income[4]				
A	8 823	5 294	955	37 205	808	220	0	1 323	54 628	44 117	37 835	81 952	27 324	2.67	10 234
B	11 470	5 294	1 176	58 823	1 102	367	0	2 058	80 290	66 176	25 693	91 869	11 579	4	2 895
C	10 588	5 294	3 676	58 823	0	0	0	1 617	79 998	82 352	37 835	120 187	40 189	4	10 047
D	11 470	5 294	2 573	88 235	0	0	0	2 205	109 777	95 588	28 375	123 963	14 186	4	3 547
E	7 647	5 294	3 676	58 823	0	220	582	2 205	78 447	55 882	26 352	82 234	3 787	2.67	1 418
F	44 117	26 470	44 117	414 705	16 911	5 147	4 411	14 705	570 583	588 235	28 235	616 470	45 887	33.33	1 377
G	35 294	15 882	13 235	514 705	14 705	3 676	2 941	22 794	623 232	705 882	19 764	725 646	102 414	26.67	3 840
H	38 235	10 588	14 705	485 294	9 558	1 470	2 205	18 382	580 437	588 235	19 764	607 999	27 562	26.67	1 033
I	28 676	10 588	11 764	294 117	6 617	1 470	0	13 970	367 202	397 058	12 705	409 763	42 561	20	2 128

[1] As some fish farmers rent ponds at different rates, pond rental costs were calculated as mean costs.

[2] Labour costs assumed that each worker was paid 220 US$/month.

[3] Utilities primarily refer to water and electricity costs.

[4] Other income refers to income generated from other farming activities, e.g. income derived from the sale of other fish species and/or livestock.

Source: Field survey (2010).

TABLE 16

The relative farm input costs at each of the surveyed fish farms (% total cost)

Farm code	Pond rental	Labour	Utilities	Feed	Drug	Feed additive	Probiotics	Fish seed
A	16.15	9.69	1.75	68.11	1.48	0.40	0.00	2.42
B	14.29	6.59	1.47	73.26	1.37	0.46	0.00	2.56
C	13.24	6.62	4.60	73.53	0.00	0.00	0.00	2.02
D	10.45	4.82	2.34	80.38	0.00	0.00	0.00	2.01
E	9.75	6.75	4.69	74.98	0.00	0.28	0.74	2.81
F	7.71	4.63	7.71	72.49	2.96	0.90	1.03	2.57
G	5.65	2.54	2.12	82.39	2.35	0.59	0.71	3.65
H	6.58	1.82	2.53	83.50	1.64	0.25	0.51	3.16
I	7.76	2.87	3.18	79.62	1.79	0.40	0.60	3.78

Source: Field survey (2010).

TABLE 17
Income derived from reared species and their proportion to the total income for each farm

Farm code	Species	Income (US$/year)	Proportion of total income (%)
A	Nile tilapia	44 117	57.39
	Duck	18 823	24.49
	Chicken	4 517	5.88
	Grass carp	8 470	11.02
	Crucian carp	941	1.22
B	Nile tilapia	66 176	72.03
	Duck	21 176	23.05
	Crucian carp	1 129	1.23
	Bighead carp	3 388	3.69
C	GIFT tilapia	88 235	69.99
	Duck	35 294	28.00
	Bighead carp	2 541	2.02
D	Nile tilapia hybrid*	95 588	77.11
	Chicken	25 411	20.50
	Bighead carp	2 964	2.39
E	Nile tilapia hybrid*	55 882	67.95
	Duck	23 529	28.61
	Bighead carp	2 823	3.43
F	GIFT tilapia	588 235	95.42
	Bighead carp	28 235	4.58
G	GIFT tilapia	705 882	97.28
	Bighead carp	19 764	2.72
H	GIFT tilapia	588 235	96.75
	Bighead carp	19 764	3.25
I	GIFT tilapia	397 058	96.90
	Bighead carp	1 2705	3.10

*Nile tilapia hybrid (*Oreochromis niloticus* × *O. aureus*).

Source: Field survey (2010).

4. DISCUSSION

4.1 Feed management

The survey revealed that the majority of farmers did not feed their fish according to the proscribed rates suggested by feed tables, and failed to take into consideration ambient temperature, body mass and pond biomass when determining feed rations. Furthermore, farmers tended to keep poor feed records. In this regard, it is interesting to note that the one farmer in the survey that kept feed records and adjusted feed rates according to the proscribed feed tables reported the best FCR in the survey. There is therefore a clear need to train famers in feed management systems, promote the use of feed tables, and ensure that farmers maintain adequate feed records.

On-farm feed storage periods were in the region of two to three weeks. While this period may be acceptable during cooler months, cold storage systems are not used and this may lead to a deterioration in feed quality in the warmer summer months. Poor feed storage is a particularly important problem associated with the use of moist feeds, and the vitamin mixes that are easily degraded. Many farmers 'top dressed; their feeds with supplements in the belief that they improved the quality of the feeds. While this increased costs, there was no evidence of the efficacy of this action. In terms of feed storage, it is recommended that farmers store their feed on their farms for as short a period as possible. This will reduce the potential for the nutritional quality of the feeds to deteriorate prior to use.

Farm made-feeds reduce investment costs and are used by the poorer farmers. However, processing and formulation techniques need to be improved; to ensure the quality of feed, small batches should be made so that they are not stored for long periods prior to use. Where farmers can afford them, high quality extruded feeds should be used. Although investment costs are higher, the economic returns are greater, and the environmental impact associated with their use is lower than those associated with farm-made feeds.

Farmers often store their feed in substandard conditions. While storage structures varied between farmers, it was evident that feed spoilage due to rain and the opportunistic consumption by animals (e.g. rodents) was problematic. In this regard, there is a need to improve on-farm storage systems so that the feed is kept away from moisture and animals.

4.2 Culture systems

Polyculture has a long history in China, and to optimize feed use and animal wastes it is normally integrated with livestock farming. Fish farmers culture several fish species, and in doing so take full advantage of natural pond productivity, and in addition, maximize water use. Farmers in Guangdong province commonly rear livestock such as ducks, chicken, and pigs on their farm land or on the pond dykes. Farmers use livestock faeces as fertilizers to promote natural productivity in their ponds. They also plant grass or vegetables in the pond mud, which serve as a feed for herbivorous fish or livestock. Though pond rental is high in Guangdong province, the incomes from livestock accounted for 20 percent to 30 percent of total income, which still provides farmers with good economic returns on their farming operations.

In contrast, in the integrated farming systems, it is hard to control the amount of faeces applied to the ponds because ducks excrete directly into the water. In such cases, pond waters can easily become eutrophic, resulting in water quality problems, and in some cases promoting fish diseases and economic losses. Integrated tilapia farming is a cost effective farming method that is suitable for adoption by small-scale farmers. Feed supply and maintaining hygienic culture conditions can be a problem in the rural areas, and large amounts of faeces released into water may cause eutrophic waters, or even food safety problems. To reduce these risks is important to ferment the faeces prior to use.

4.3 Water quality management

Water quality in the ponds in Guangzhou, Guangdong province was found to be poor. This was attributed to two main reasons. Firstly, water supplies were of a poor quality and were likely to be sub-standard in terms of promoting optimal production. Farmers reported that, due to shortages in the area, the quality of the water that was available to them was becoming worse over time. Secondly, farmers operated their systems at relatively high densities and integrated their production systems with terrestrial livestock. The use of faecal material as a pond fertilizer often results in the development of eutrophic conditions. To reduce production costs, the fish farmers generally refused to use probiotics. The economic returns from fish farming are currently greater than those associated with traditional terrestrial farming and, as a result, many landowners are increasingly entering the sector, placing further pressure on the limited water resources. Furthermore, poor water quality is often associated with an increased incidence of disease, poor product quality, and lower market prices.

Managing pond waste waters is a serious issue in China. Environmental impact assessment agencies operate at the central, provincial and local government levels and are primarily concerned with the environmental impacts associated with industrial wastewater discharges. Normally they ignore the issues associated with waste water discharge from aquaculture ponds. The Ministry of Agriculture of China (MoA) and the attached agricultural bureaus at provincial and local levels are the responsible agents for regulating and monitoring water intake and effluent discharge. In 2007, the MoA developed standards for water quality discharges from freshwater aquaculture ponds (Table 18). Two levels of standards are given. If the effluent waters are discharged into drinking water sources, hatcheries or first class ecological reserves, the water must comply with the 'first class standards'. If the effluent waters are discharged into other water bodies, the 'second class standards' apply.

TABLE 18
Standards for waste water discharged from freshwater aquaculture ponds

Items	First class standards	Second class standards
Suspended matter (mg/l)	≤50	≤100
pH	6.0–9.0	6.0–9.0
COD (mg/l)	≤15	≤25
BOD (mg/l)	≤10	≤15
Zinc (mg/l)	≤0.5	≤1.0
Copper (mg/l)	≤0.1	≤0.2
Total phosphorus (mg/l)	≤0.5	≤1.0
Total nitrogen (mg/l)	≤3.0	≤5.0
Sulphide (mg/l)	≤0.2	≤0.5
Total chlorine (mg/l)	**≤0.1**	**≤0.2**

Source: MoA (2009).

In practice, it is very difficult to implement these water quality standards and, unless the waste water is discharged into drinking water sources or reserves containing endangered species, it is normally difficult to have the discharges monitored. The costs associated with monitoring are high and fish farms are widely dispersed, making monitoring expensive and difficult to implement. In future there will be an increasing need to monitor effluents arising from aquaculture operations.

The Ministry of Agriculture is also responsible for monitoring aquafeed production; in contrast to farm effluent monitoring, the feed manufacturing industry is strictly monitored.

4.4 Feed selection

Farmers assessed feed quality as the primary factor affecting their selection of feed. Farmers in Guangdong province prefer to use extruded floating feeds while farmers in Hainan province prefer to use sinking feeds. Many farmers identified the importance of using high quality feed ingredients but were unaware that feed processing also has a significant effect on feed quality. In many instances, the feedstuffs that were bought by the farmers were poorly milled and failed to conform to the feed process standards as outlined by the National feed guidelines (MoA, 2005). With feed costs accounting for up to 80 percent of production costs, there is a need to ensure that these standards are adhered to, and that cost effective high quality feeds are available to the farmers. Furthermore, there is also a need to develop high quality low-cost feeds, using cheap protein sources.

5. RECOMMENDATIONS

The following recommendations should be implemented to improve feed and feed management:

- On-farm feed management was generally found to be acceptable; however improved feed efficiencies could be attained by improving feed management protocols.
- Feed manufacturers should develop feed tables to optimize ration sizes. These should be distributed to the farmers and used to improve their feed management practices.
- Prior to being used, feeds are currently stored on the farm for periods of up to two to three weeks; ideally this period should be reduced.
- Where possible, high quality extruded feeds should be used; although the price of these feeds is higher than their farm-made counterparts, they promote improved growth and FCR and minimize environmental pollution.
- On many farms, feed storage facilities should be improved; this will minimize losses to pests and assist in maintaining feed quality.

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On-farm feed management practices for Nile tilapia *(Oreochromis niloticus)* in Egypt

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ABSTRACT

Between February and May 2010 a survey was undertaken to evaluate on-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Egypt. Data were obtained from 64 tilapia farmers and 6 aquafeed mills from the three major tilapia production governorates (Kafr El-Shaikh, Behaira and Sharkia), which produce over 80 percent of the farmed tilapia in Egypt. The results of the survey indicated that the production of farmed Nile tilapia increased from only 24 916 tonnes in 1990 (2.28 percent of total aquaculture production) to 386 186 tonnes (55.7 percent) in 2008. Tilapia culture in Egypt is primarily practiced in semi-intensive systems in brackishwater ponds. In 2008, over 80 percent of production (315 253 tonnes) was undertaken in semi-intensive systems. Nevertheless, tilapia polyculture systems, incorporating mullets and carps, remain a common practice in many areas; however, they are gradually being replaced with monoculture all-male Nile tilapia. About 75 percent of the surveyed tilapia farmers in these areas adopt mono-sex tilapia culture. Intensive Nile tilapia culture practices in earthen ponds, tanks and cages are slowly spreading in many areas of the country.

There are no standardized feeding and fertilization strategies, and the majority of the tilapia farmers do not apply the correct regimes. Poultry manure is the most important organic fertilizer used. It is estimated that about 6 to 7 percent of the poultry manure available in Egypt is used in aquaculture. In some areas, tilapia farmers no longer use organic fertilizers but fertilize their ponds with chemical fertilizers. This is only undertaken prior to the stocking of fish; both urea and superphosphate are generally used. Fertilization rates are typically between 20 to 40 kg superphosphate per hectare (average ~30 kg/ha), in addition to 10 to 25 kg of urea/ha (average 20 kg/ha).

Currently, the commercial aquafeed manufacturing industry in Egypt is expanding rapidly. The number of aquafeed mills increased from only 5 in 1999, to 31 in 2009. Current aquafeed production is approximately 420 000 tonnes/year, about 280 000 tonnes (65 percent) of which is used for tilapia. Sinking pellets, with a crude protein (CP) content of 25 percent are predominant. However, extruded aquafeed technology was introduced in Egypt in the mid-1990s; tilapia farmers prefer them as they are better digested and converted to body mass. The feed conversion ratios (FCR) attained when using pelleted Nile tilapia feeds range

from 1.5:1 to 2.5:1, while those for extruded feeds range from 1.1:1 to 2:1. Hand feeding, twice per day (early morning and late afternoon) is the most common feeding practice. However, the use of locally-made demand feeders is expanding, especially among medium to large-scale farmers. It is estimated that the use of processed feeds contributed about 48 percent of total tilapia production; the rest is attributed to natural food attained by pond fertilization. Farm-made feeds are rarely used by Egyptian tilapia farmers; none of those surveyed used them.

Fifty to seventy-five percent of the ingredients used in aquafeeds in Egypt are imported. As a result, prices have been increasing substantially; in consequence the prices of both pelleted and extruded tilapia feeds have increased 2 to 2.5 times over the past decade. The major constraints faced by tilapia farmers and the aquafeed manufacturing industry include the escalating price of processed feeds and feed ingredients, high customs tariffs on feed ingredients, the poor handling and storage of feed ingredients and finished feeds, access to finance for the small scale producers, and the unavailability of larval and fingerling feeds. Recommendations to address these issues are provided in this report.

1. INTRODUCTION

Tilapia are freshwater cichlid fish that, while native to Africa, were introduced into many tropical, subtropical and temperate regions of the world during the second half of the 20th century (Pillay, 1990; El-Sayed, 2006). They have many attributes that make them excellent candidates for aquaculture, including fast growth rates, a high tolerance to a wide range of environmental conditions, resistance to stress and disease, the ability to reproduce in captivity, a short generation time, the ability to feed at a low trophic level, and the acceptance of artificial feeds immediately after yolk-sac absorption. It is believed that tilapia culture originated about 4 000 years ago (Balarin and Hatton, 1979). During the past two decades, global tilapia culture has increased significantly; currently about 100 countries rear tilapia. As a result, global production of farmed tilapia has increased from 383 654 tonnes in 1990 (2.28 percent of total aquaculture production) to 2 505 452 tonnes in 2007 (2.93 percent). The average annual production growth rate during this period approached 13 percent and tilapia now ranks as second only in importance to carps (Fitzsimmons, 2008). This author also predicted that tilapia would become the most important aquaculture crop in this century, continuing to be a preferred source of income and protein for impoverished rural communities in developing countries.

Semi-intensive tilapia culture has been adopted in various parts of the world, either in monoculture or polyculture systems. Recently semi-intensive tilapia culture with other herbivorous/omnivorous fish such, as carps (common carp *Cyprinus carpio*; silver carp *Hypophthalmichthys molitrix* and grass carp *Ctenopharyngodon idella*) and mullets (flathead grey mullet, *Mugil cephalus* and thinlip grey mullet, *Liza ramada*) has seen significant expansion, particularly among small-scale farmers in Asia, Africa and Latin America. In recent years there has been a rapid, global industrialization of tilapia production. This has lead to a gradual shift in tilapia culture from traditional, low-input, semi-intensive systems to more intensive farming practices, with an increasing dependence on formulated feeds. In many regions this has created a disparity between seed supplies and demand, and a concomitant increase in demand for formulated feed. Currently, the major challenge facing the tilapia culture industry is the production of sufficient amounts of quality seed. The formulation of appropriate feeds in order to optimize reproductive outputs, seed production and growth performance, is also a key factor for promoting tilapia culture. Commercial tilapia culture is currently restricted to about 10 species. However, the Nile tilapia (particularly mono-sex male populations) is by far the most important species; between 1970 and 2008 the production of farmed Nile tilapia represented more than 80 percent of the total global production of farmed tilapia.

Tilapia culture has traditionally been practiced in Egypt for thousands of years. An

Egyptian tomb frieze dated at about 2500 B.C. depicts a tilapia harvest, and suggests that fish may have been cultured for human consumption (Chimits, 1957; Bardach, Ryther and McLarney, 1972). However, the first modern commercial tilapia farm was built in 1957 at Manzala (near Mansoura, Dakahlia governorate) and operated by the Egyptian government. This farm had a total area of 440 ha of earthen ponds, and was used for growing Nile tilapia, common carp and flathead grey mullet in polyculture systems (Eisawy and El-Bolok, 1976).

Nile tilapia (Figure 1) is currently the only cultured tilapia species. A tilapia hybrid (Florida red tilapia) was introduced into Egypt in the 1980s but rearing trials almost ceased in response to consumer dislike of the hybrid and preference for Nile tilapia. It was only during the 1990s that Nile tilapia was recognised as an important aquaculture species. This recognition was associated with the expansion of semi-intensive culture systems in earthen ponds. The expansion was driven by private fish farmers and the development of privately-owned hatcheries and feed mills.

FIGURE 1
Harvested Nile tilapia

COURTESY: FAO/A.-F.M. EL-SAYED.

As a result of the continuous development of tilapia aquaculture in Egypt, the production of farmed tilapia increased from only 24 916 tonnes in 1990 (2.28 percent of total aquaculture production) to 386 186 tonnes in 2008 (55.7 percent), as shown in Table 1 and Figure 2). As a result, Egypt is now the second largest tilapia producer in the world, after China.

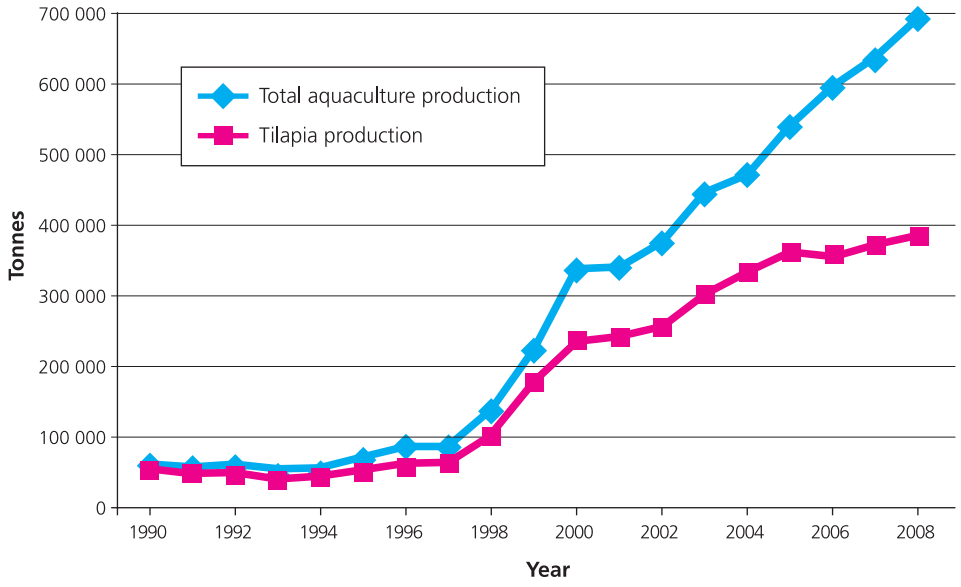
TABLE 1
Aquaculture production (tonnes) by species and production system in Egypt in 2008

Category	Production system				Total	Percent of total production
	FW ponds/tanks[1]	BW ponds[2]	Cages	Rice fields		
Nile tilapia *(Oreochromis niloticus)*	1 602	363 126	10 458	11 000	386 186	55.66
Mullets *(Mugil cephalus; Liza ramada)*		150 663	58 650		209 313	30.17
Carps *(Cyprinus carpio, Hypophthalmichthys molitrix; Ctenopharyngodon idella)*		61 805		11 400	73 205	10.55
North African catfish *(Clarias gariepinus)*	120	8 324		5 500	13 944	2.00
Gilthead seabream *(Sparus aurata)*	50	4 430			4 480	0.65
European seabass *(Dicentrarchus labrax)*	50	4 333			4 383	0.62
Meagre *(Argyrosomus regius)*		2 031			2 031	0.29
Others[3]		273			273	0.06
Total	**1 822**	**594 985**	**69 108**	**27 900**	**693 815**	**100**

[1]Freshwater intensive pond; [2]brackishwater semi-intensive ponds; [3]including shrimp *(Penaeus japonicus, P. semisulcatus)*, bayad *(Bagrus bagrus, B. bayad)* and Nile perch *(Lates niloticus)*.

Source: GAFRD (2009).

FIGURE 2
Aquaculture production in Egypt, 1990–2008



Source: GAFRD (2009).

All-male Nile tilapia currently represents a substantial proportion of farmed tilapia production. All-male, mono-sex tilapia populations are produced using an oral administration of 17α-methyltestosterone (MT). The hormone is generally incorporated into larval feeds at a dose of 30 to 60 mg/kg and administered to undifferentiated, swim-up larvae (5–8 days after hatch; 1 to 2 days after yolk sac absorption) for 25 to 30 days. The process produces about 85 to 95 percent males. Tilapia broodstock and larvae are generally fed with diets containing relatively high protein levels (30 to 35 percent), compared to the 25 percent protein diets that are commonly used during the rest of the production cycle.

Almost all-small scale farmers buy their tilapia seeds (both mono-sex and mixed-sex) at 2 to 5 g from commercial hatcheries. Hatcheries are located in most of the tilapia production areas. In addition, most large-scale tilapia farmers in Kafr El-Shaikh, Behaira and Sharkia produce both mono-sex and mixed-sex tilapia for their own farms, and also for selling to other farmers in the region. The peak of production and selling of hatchery-produced tilapia fingerlings is generally at the beginning of farming season (May and June). Usually, farms only produce one crop per annum, with the fish being harvested in November and December, or overwintered through December till March/April.

The development of tilapia culture depends, amongst other factors, on the availability and accessibility of inputs, including feeds and fertilizer resources. Information relating the source, nature, quantity, quality, price, seasonality, production, import, export and distribution of feeds and fertilizers among the various users and stakeholders is required to maintain a successful tilapia culture sector. Currently there is a paucity of information related to the availability of feed and fertilizer resources that are used for tilapia culture in Egypt. In addition, the available information suggests that there are no specific standards for feeding and fertilization regimes. Farmers in different geographical regions adopt different feeding and fertilization strategies; these may also vary between farmers within the same region. Therefore, in-depth analyses of existing aquafeed and fertilizer management practices, and the promotion of better management practices, are an essential prerequisite to the development of sustainable, cost-effective tilapia culture in Egypt.

This study reviews the current status and trends in fertilizer and feed use in Egypt. Information on the availability, accessibility, and utilization of these resources for

different farming systems has been collected and synthesized. This information can be used to assist fish farmers (especially tilapia farmers) and aquafeed producers to maximize their use of the available feed inputs. It will also enable the government authorities and other concerned stakeholders/organizations/associations to make appropriate decisions to promote aquaculture development and sustainability.

The objectives of the study were to:

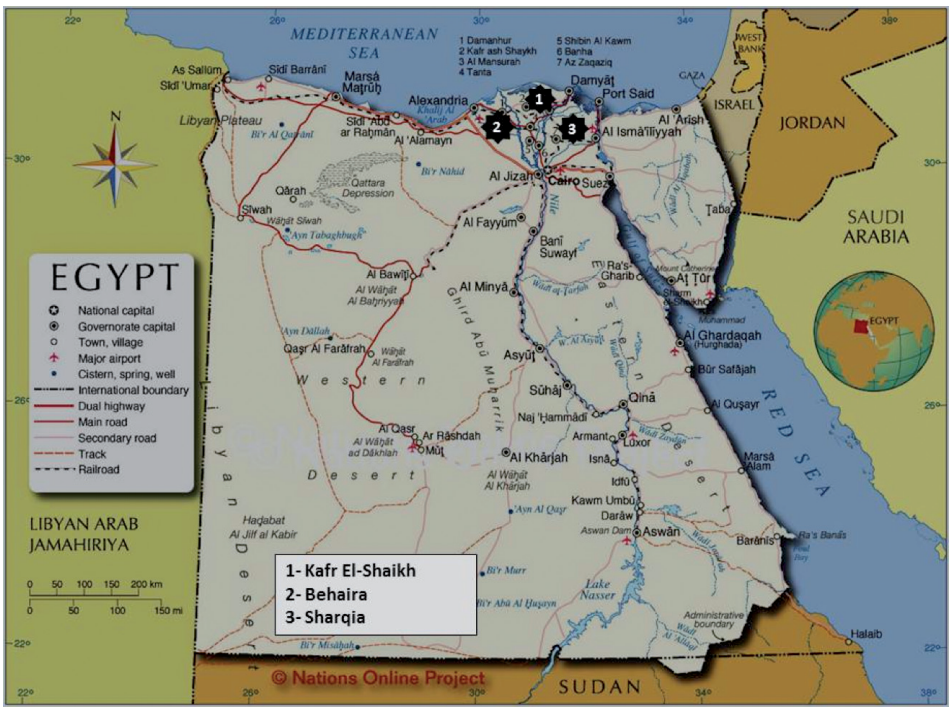
- Evaluate the use of processed feeds, farm-made feeds and fertilizers in the major areas where tilapia culture is practiced.
- Conduct a cost-benefit analysis of these resources to compare production costs.
- Identify the further potential for tilapia feed production in Egypt.
- Identify the main constraints to tilapia feed management practices, and suggest appropriate solutions to these constraints.

2. METHODS

A structured questionnaire was developed and distributed during February and May 2010 to a randomly selected group of small and large-scale tilapia farmers; these comprised a representative sample from the major production governorates, namely Kafr El-Shaikh, Behaira and Sharkia (Figure 3). Tilapia production from these governorates accounts for over 80 percent of total farmed tilapia in Egypt. The majority of tilapia farms here are small-scale, semi-intensive pond farms. Tilapia cage farms are restricted exclusively to Rashid (Rosetta) Branch of the Nile in Behaira and Kafr El-Shaikh governorates. Based on the type of farming practices and the number of tilapia farms in each of the three governorates, farms were randomly selected to provide a representative sample of the different types of culture facility. Sampling was also designed so that the surveys covered the widest possible geographical area.

Initially, the questionnaires were distributed through field visits and via phone calls to the farmers. However, the due to problems associated with using these methods,

FIGURE 3
Map of Egypt showing the three study governorates



Source: www.nationsonline.org

technicians and aquaculture consultants were employed to assist in the deployment of the survey. A similar questionnaire to that used for the farmers was developed for the aquafeed industry and distributed among 6 aquafeed mills (4 private and 2 public). The surveys were collected through field visits or via phone and/or E-mail. A total of 64 farmers responded to the questionnaire (Table 2) and six aquafeed mills responded (4 private and 2 public).

TABLE 2
Sample allocation in the three main tilapia culture governorates in Egypt

Governorate	Culture facilities surveyed				Total	Areas surveyed
	Semi-intensive ponds	Intensive ponds	Intensive tanks	Intensive cages		
Kafr El-Shaikh	23	1	1	3	28	Hamool, Baltim, Borullus and Desouk
Behaira	14	2	2	8	26	Barsiq, Maadia, Edco, Rashid (Rosetta) and West Nubaria
Sharkia	9	1			10	Abbasa, Abou Hammad, Salhia
Total	**46**	**4**	**3**	**11**	**64**	

Source: Field survey (2010).

The information obtained from the surveys was collated, tabulated and sorted into different categories, *viz.*:

- Farming system (semi-intensive, intensive tank, intensive pond and intensive cage culture).
- Cultured species (mixed-sex tilapia, mono-sex tilapia and polyculture).
- Ownership (private and governmental).

All data were coded and entered into a Microsoft Excel spreadsheet for statistical analysis, primarily comprising simple descriptive statistics.

3. RESULTS AND DISCUSSION

Nile tilapia are reared in several types of systems in Egypt, including semi-intensive pond culture, intensive cage culture, intensive pond culture and intensive tank culture.

3.1 Semi-intensive pond culture

Semi-intensive tilapia culture is primarily practiced in brackishwater environments, particularly around the northern delta lagoons. Semi-intensive fish culture in earthen ponds is by far the most important farming system and accounted for 84 percent of aquaculture production in Egypt in 2008. Semi-intensive production in earthen ponds increased from 191 000 tonnes in 1999 to 315 253 tonnes in 2008; currently it accounts for 45 percent of total aquaculture production (693 815 tonnes) and 82 percent of total tilapia production (386 186 tonnes) (Table 1). Pond culture is primarily practiced mainly by private sector. In 2008, the private sector produced 685 268 tonnes of tilapia, equating to about 99 percent of total pond production. In contrast, the governmental sector produced only 8 547 tonnes (~1 percent). The major producing governorates for pond production were Kafr ElShaikh, Sharkia, and Behaira. In 2008, these governorates accounted for about 80 percent of pond tilapia production. Moreover, Kafr El-Shaikh alone produced 173 371 tonnes, representing 43.8 percent of total tilapia production (GAFRD, 2009).

3.1.1 Pond preparation

Survey results suggest that semi-intensive tilapia culture in earthen ponds is the dominant farming activity in the study areas (>90 percent). Tilapia ponds, particularly in and around the northern Delta lakes, are typically constructed by enclosing parts of the shallow coastal areas and dividing them into fish ponds. Ponds are also constructed in depressed irrigated or saline lands. Pond depths range from 70 to 150 cm, with an average of ~1 metre. Minimal attention is paid to pond preparation. Most tilapia ponds are drained for harvesting and remain dry for long periods (3 to 4 months). Most tilapia farmers harvest their crops in early winter, as the fish cannot tolerate the severe drop in water temperature in winter. However, some polyculture farmers extend the production cycle throughout the year (or more). Drained ponds remain dry from December/January to April. The majority of semi intensive farmers do not apply specific pond preparation strategies. Drained and harvested ponds are simply left to dry until the mud surface cracks. One reason why pond preparation and maintenance is low is that most of small-scale farmers do not have official rental or ownership contracts. Instead, they informally rent their ponds from large-scale farmers or land owners at much higher rental rates than the governmental rates. Therefore, those farmers generally refuse to add inputs to the ponds as they have unsecured tenure. Occasional removal of the mud layer and the tilling of the pond soil before pond filling takes place in governmental tilapia farms. Very few private pond farmers till their ponds.

3.1.2 Cultured species

Typically, Nile tilapia (*Oreochromis niloticus*), mullets (flathead grey mullet *Mugil cephalus* and thinlip grey mullet *Liza ramada*) and carps (mainly common carp; grass carp and silver carp are occasionally used) are reared semi-intensively in earthen pond polyculture systems. In 2008, the combined production of these three groups from semi-intensive systems accounted for 82 percent of total aquaculture production (45.4 percent, 30.2 percent and 6.5 percent, respectively). The fish are stocked at 5 000 to 15 000 fish/feddan (12 000 to 40 000 fish/ha). Stocking ratios vary considerably. However, tilapia accounts for 60 to 80 percent of the stocked fish. The stocking sizes of tilapia, mullets and common carp are 2 to 10 g, 20 to 50 g and 5 to 20 g, respectively. Mullets are generally nursed separately at high densities for about 6 to 8 months, until they reach the required size. The cultured species are stocked in April/May in order to reach market size at about the same time, namely after 8–10 months.

However, in many areas, particularly in Behaira governorate (Edko and Rashid), polyculture systems are becoming less common, and are being replaced by monoculture systems producing all-male Nile tilapia. This is mainly due to the low acceptance of cultured carp in these areas, insufficient mullet seed supplies, the higher growth rates associated with all-male tilapia, and market acceptance. About 75 percent of surveyed tilapia farmers in these areas farm mono-sex tilapia. Monoculture of mixed-sex tilapia is still a common practice in many areas in Kafr El-Shaikh and Sharkia governorates. The production of semi-intensive systems varies from 3.5 to 10 tonnes/ha/production cycle (6 to 10 months).

3.1.3 Pond fertilization – organic

In semi-intensive tilapia culture systems, almost all small-scale farmers depend on poultry manure for fertilization. Fertilization rates range from 2 to 4 tonnes/ha. Generally, prior to filling, the farmers spread the dry fertilizer on the pond bottom (Figure 4). Other farmers pile the dry manure on the pond dikes and spray it with water for few days, before washing it into the ponds. In comparison to applying dry manure, this process enhances decomposition processes and reduces the time needed to maximize primary production. The nutrient composition of the major manures in Egypt is provided in Table 3.

FIGURE 4
Piling organic fertilizers on pond bottoms before filling with water

COURTESY: FAO/A.-F.M. EL-SAYED.

TABLE 3
Nutrient composition (%) of selected manures

Manure	Dry matter	Nitrogen	Phosphorus	Potassium	Organic matter	N:P ratio	C:N ratio
Chicken	68.00	3.40	1.75	1.67	39.00	1.90	8.00
Duck	74.00	2.00	1.30	1.20	41.00	2.00	9.00
Buffalo	72.00	1.90	0.70	1.20	36.00	3.50	22.00
Cow	76.00	2.10	0.80	1.10	38.00	3.30	20.00
Goat	71.00	0.80	0.10	0.10	32.00	4.10	17.00
Sheep	73.00	1.00	0.20	0.20	34.00	3.80	18.00

N:P = nitrogen: phosphorus; C:N = carbon: nitrogen.
Source: El-Sayed (1999).

In some cases, fresh manure is used directly for pond fertilization, particularly in Sharkia and Behaira governorates, where livestock production is commonplace. Fresh manure may be preferred to dry manure as it disintegrates in water into colloidal particles that are easily accessible to bacteria, and the nutrients are readily incorporated into food web.

The majority of farmers are not familiar with fertilization protocols (rates, quantities, frequencies, etc.). Poor fertilization practices may lead to deterioration in water quality and fish mortality. A number of farmers in Kafr El-Shaikh and Behaira Governorates reported massive mortality of farmed tilapia due to the excessive application of organic fertilizers (El-Sayed, 2006, 2007). In some areas of Behaira governorate (Edko, Rashid), tilapia farmers no longer use organic fertilizers. Instead, prior to stocking, they fertilize their ponds with inorganic fertilizers and apply supplemental feeding based on commercial pellets for the entire production cycle.

3.1.4 Pond fertilization – inorganic

The use of inorganic fertilizers in pond fertilization is limited. About 10 percent of the surveyed semi-intensive farmers apply inorganic fertilizers alone, while 26 percent used mixtures of both inorganic and organic fertilizers. The majority apply inorganic fertilizers only once at the beginning of the production cycle. A small proportion of farmers apply inorganic fertilizers (generally at 15-day intervals) when the productivity of the ponds decreases. Both urea and superphosphate are used. The ratio and amounts applied vary considerably between farmers and farming areas. Normally application rates are between 20 to 40 kg superphosphate per ha (average: ~30 kg/ha), and 10 to 25 kg of urea (~20 kg/ha).

There are no accurate records on the volumes of inorganic fertilizers currently used. However, it is estimated that between 600 to 1 000 tonnes of urea and 900 to 1 500 tonnes of superphosphate (a total of 1 500 to 2 500 tonnes) were used in 2008 for pond fertilization. At these application rates competition with field crops for inorganic fertilizer is unlikely to occur, at least in the short term. In the foreseeable future, organic fertilizers are expected to remain the major source of fertilizers that are applied.

3.1.5 Supplemental feed and feeding practices

The majority of monoculture and polyculture farmers only fertilize their ponds prior to fish stocking; seldom afterwards. Many farmers start feeding tilapia with commercial feed (25 percent protein) as early as 3 days after stocking. This is probably not the best husbandry policy as well-fertilized ponds provide sufficient natural food for cultured fish at this time, and supplemental feeding can be delayed by up to 2 months. Abdelghany, Ayyat and Ahmad (2002) found that when Nile tilapia ponds (reared with common carp and silver carp) were fertilized bi-weekly with 750 kg chicken litter, 100 kg triple superphosphate and 20 kg urea per ha, supplemental feeding could be delayed for up to 6 weeks without any reduction in fish yields; this resulted in a significant reduction in feed costs. Green, El Nagdy and Hebicha (2002) reported that first feeding could be delayed to up to 60 days. Similarly, Diana, Lin and Yi (1996) found that Nile tilapia can be grown up to 100 to 150 g with fertilizers alone, while feeding the fish before they reach this size is wasteful (Table 4).

TABLE 4

Feed and fertilization strategies suggested for optimum yield of tilapia in semi-intensive systems

Cultured tilapia			Fertilization regime	Feeding	Culture period (days)	Yield (tonnes/ha)	Remarks	Reference
Species	Size at stocking (g)	Density (no./ha)						
Nile tilapia male	1–3	20 000	Chicken manure, 1 000 kg/ha/week for 60 days 54.4 kg urea plus 92.4 kg super phosphate/ha/week	30% CP* diet, 3% BW**/ day, feeding starts at day 60	145	7.40	African catfish (59 g) were used for controlling over-population of tilapia	Green, El Nagdy and Hebicha (2002)
				No feeding		3.20		
Nile tilapia Silver carp Common carp	13.8 1.9 10.7	30 000	750 kg chicken litter/ha, bi-weekly application, plus 100 TSP and 20 kg urea/ha	25% CP diet, 3% BW/day, 6 weeks after stocking.	133	4.75	Feeding at 6-week delay was comparable to no delay, and better than at 13-week delay.	Abdelghany, Ayyat and Ahmad (2002)
Nile tilapia (85%) + catfish (15%) + 300 silver carp	0.3 132 100	30 000–50 000	Chicken litter (550 kg/ha/week) or monophosphate (72.5 kg/ha/week) and urea (45 kg/ha/week)	25% CP floating pellets, twice a day, to satiation, 60 days after stocking	190	4.9–8.6	Best growth at 3 fish/m^3, regardless of type of fertilizers	El Naggar, Ibrahim and Abou Zead (2008)

*CP = crude protein; **BW = body weight.

At present, there is a gradual shift among small- and medium-scale tilapia farmers to move from relying on pond fertilization to external feeding. About 70 percent of the surveyed pond farmers use commercial pellets throughout the entire production cycle, particularly in Behaira Governorate (Edko, Rashid and Maadia) and Kafr El-Shaikh governorate (Khashaa, Hamool and Baltim).

The majority of tilapia farmers (65 percent of those surveyed) use sinking pellets, while the remaining 35 percent use extruded (floating) pellets. Generally, 30 to 35 percent CP diets are used for fingerlings; 25 percent CP feeds are used later in the production cycle. However, many farmers use 25 percent CP throughout the whole production cycle.

Hand feeding, twice a day (at 07.00 to 08.00 and 16.00 to 17.00 hours), is the most common feeding practice among small-scale tilapia farmers. Most do not feed the fish at a calculated percent of their body weight per day; they simply provide given quantities of feed based on their previous experience, and it is likely that they are underfeeding their fish. This assertion is reflected by the reported productivity of the ponds, which is generally lower than that reported in other countries (El-Sayed, 2006).

The use of locally-made, cheap demand feeders (Figure 5) is spreading, especially among the medium- to relatively large-scale farmers. These feeders comprise a cone-shaped plastic, metallic or glass fibre hopper, with a narrow opening at the bottom. A steel free-swinging activator rod is inserted from the middle of the opening and positioned below the hopper to about 10 to 15 cm under the water surface. When the fish touch or activate the rod, feed pellets are allowed to slowly drop on the water surface. The application of these feeders enables the fish to eat only when hungry. Normally, between 8 to 12 feeders per ha are deployed at fixed distances along the pond sides.

FIGURE 5
Demand feeders commonly used for feeding tilapia in semi-intensive and intensive systems

COURTESY OF FAO/A.-F.M. EL-SAYED.

The feed conversion ratio (FCR) of pelleted feeds for Nile tilapia raised in semi-intensive systems varies considerably, and is dependent on the fish stocking size, densities, and fertilization regimes. The FCR attained using pelleted feed for fingerlings ranges from 1.7:1 to 2.1:1, while that for floating feeds range from 1.2:1 to 1.6:1. For the fattening stages of the production cycle, the FCR of pelleted and extruded feeds range from 1.3:1 to 1.8:1 and 1:1 to 1.4:1, respectively. It should be emphasized that these values may be misleading, as natural feeds are an inherent component of total food consumption; thus, making FCR determinations is problematic.

3.1.6 Production cycle and harvest

As a result of inappropriate feed and fertilization regimes in tilapia ponds, fish yields are relatively low compared with well-fertilized, well-fed ponds in other countries. The yields range between 3 to 6 tonnes/ha/production cycle (about 6 to 8 months). There are a few exceptions, where production in monoculture can reach 8 to 10 tonnes/ha/cycle; however, in these cases the production cycle is generally longer (9 to 11 months).

A longitudinal ditch, about 50 cm deeper than the main pond, is generally dug at one side for fish wintering and harvesting. When the pond is drained, the fish are forced to move into the ditch. Fish harvesters pull the fish to one end of the ditch using nets, where they can be removed using scoop nets (Figure 6). The production cycle, stocking sizes, feeding schedules and the common use of fertilizers in polyculture systems is summarized in Table 5.

FIGURE 6
Harvesting Nile tilapia in semi-intensive ponds in Kafr El-Shaikh, Egypt

Source: www.nationsonline.org

TABLE 5

Production cycle, feeding schedules and common use for fertilizers for Nile tilapia in polyculture systems in Egypt

Month	Size (g)			Feeding schedules			Type of fertiliser	
	Nile tilapia	Mullet (*M. cephalus*)	Common carp	Feed type	Feeding frequency per day	Feeding rate (% of body weight)	Organic (poultry manure)	Inorganic superphosphate/ urea
1	2–10	20–50	5–20	Floating/ sinking	2–3 times	4–6	x	x
2	5–20	30–70	10–30	Floating/ sinking	2–3 times	3–4	x	x
3	15–40	50–100	20–50	Floating/ sinking	2–3 times	3–4	x	x
4	30–80	80–130	40–100	Floating/ sinking	2 times/demand feeder	2–3	x	x
5	60–130	100–150	80–150	Floating/ sinking	2 times/demand feeder	2–3/satiation	-	-
6	100–170	130–180	120–200	Floating/ sinking	2 times/demand feeder	2–3% BW/satiation	-	-
7	140–220	160–220	150–250	Floating/ sinking	2 times/demand feeder	2/satiation	-	-
8	200–250 [Harvest]	200–250 [Harvest]	180–300 [Harvest]	Floating/ sinking	2 times/demand feeder	2/satiation	-	-
9	250–300 [Harvest]	230–280 [Harvest]	230–350 [Harvest]	Floating/ sinking	2 times/demand feeder	2/satiation	-	-
10	>300 [Harvest]	250 – >300 [Harvest]	280 – >400 [Harvest]	Floating/ sinking	2 times/demand feeder	2/satiation	-	-

Note: Fertilizer not used from beginning of month five.

Source: Field survey (2010); Abdelghany, Ayyat and Ahmad (2002); El-Sayed (2006); A. Kasem, personal communication, 2012; M. Soliman, personal communication, 2012; W. El-Hawwary, personal communication, 2011.

3.2 Intensive cage culture

3.2.1 Cage location and construction

Over the past decade, tilapia cage culture has been spreading rapidly throughout the country, most notably in the Domiat (Damietta) and Rashid branches of the Nile River. As a result, cage production has increased from 12 900 tonnes in 1999 to 69 108 tonnes in 2008, and currently accounts for 18 percent of total tilapia production. Cage culture is practiced exclusively by the private sector.

Rectangular and square cages measuring 32 m^3 (4 x 4 x 2 m) to 600 m^3 (10 x 10 x 6 m) are commonly used. The cages are made of wooden frames and synthetic netting. Empty, closed plastic barrels (50 litre capacity) are fixed underneath the frames to serve as floats (8 to 12 floats per 600 m^3 cage). The cages are used in the Nile (Rosetta branch) in groups or arrays (Figure 7). Professional divers are occasionally employed to monitor the cages, remove the fouling and repair any damage that may have occurred to the nets.

FIGURE 7
Culture of Nile tilapia in floating cages in Rashid branch of the Nile River

COURTESY OF FAO/A.-F.M. EL-SAYED.

3.2.2 Stocking density and feeding

Tilapia fingerlings (3 to 10 g) are stocked at 80 to 100 fish/m^3. The fish are initially fed with commercial feeds (35 to 40 percent CP, reduced to 25 to 30 percent during the latter part of the production cycle). The majority of cage farmers use extruded pellets (2–3 mm in size). If large sized overwintered fish (30 to 50 g) are stocked, they are generally fed with 5 mm pellets during the last 2 to 3 months of the production cycle. The use of floating pellets saves about 25 percent of the feed that would otherwise be lost from the cage – if pelleted feeds (sinking pellets) are used. The feeds are fed either manually (2 to 3 times per day) or from demand feeders.

Feed conversion ratios (FCR) attained using pelleted feeds in cage culture range from 1.5:1 to 2:1 for fingerlings to 1.3:1 to 1.7:1 for the grow-out period. In contrast, the FCR attained using extruded feeds range from 1.2:1 to 1.5:1 and 1:1 to 1.2:1 for fingerling and grow-out stages, respectively.

3.2.3 Production cycle and yield

Some cage farmers use the 'young-of-the year' (5 to 10 g) for stocking, while others stock over-wintered fish. After 9 to 13 months, farmed 'young-of-the year' tilapia reach about 300 to 500 g, with a total production ranging from 25 to 40 kg/m^3 (about 15 to 25 tonnes per 600 m^3 cage). Some cage farmers stock the fish at larger sizes (over-wintered, 40 to 100 g) and, in turn, reduce the production cycle to about 6–8 months.

3.2.4 Environmental impacts of cage culture

The wide expansion of tilapia cage culture in the Nile River has increased public awareness to aquaculture and created a debate among governmental authorities, academics and environmental protection bodies about the environmental impacts of these farming operations. In the past, the government removed the cages from the Damietta (Domiat) branch of the Nile, claiming that fish faeces and feed wastes from the cages were polluting the river and causing severe ecological and health problems. This action divided public opinion. Those in favour of tilapia cage culture suspect that the cages pollute the Nile but claim that this culture system is practiced globally. They suggest that removing the cages is not the solution, and that resolution could be sought by: improving management systems, such as limiting the number of cages per square kilometre; the use of high-quality feeds; optimised feeding strategies; the appropriate selection of cage sites; and the farming of other fish species such as silver carp that, as filter feeders, would reduce organic loads. Continuous governmental monitoring and inspection could certainly minimize the effects of the cages. In general, researchers, academics and farmers are in favour of this point of view. In contrast, the environmental protection authority and governorate administration claim that the cage culture activities are resulting in deteriorating water quality, and very likely constitute a health hazard. Therefore, they believe that removing the cages is the only solution to the problem. Unfortunately, removing the cages has been catastrophic for the farmers. Currently, tilapia cage culture is restricted to the Rashid branch of the Nile River.

3.3 Intensive pond culture

Intensive tilapia culture in earthen ponds is slowly spreading to many areas in Egypt, particularly in Behaira. This system is also gradually expanding in many newly reclaimed desert areas, where the culture water is subsequently used for land crop irrigation.

3.3.1 Pond preparation

In many respects pond preparation and management in intensive culture is similar to that adopted in semi-intensive systems. However the following differences apply:

- Only monoculture (mainly mono-sex) is practiced; polyculture is not applied.
- Ponds are aerated using air compressors or paddle wheels (see section 3.4.2). The number of air compressors and paddle wheels depends on the stocking density, culture stage and the levels of water replacement.
- Ponds are not fertilized, and the fish depend exclusively on formulated feeds.
- Despite the predominance of earthen ponds, the ponds walls in some areas (Nubaria and Behaira) are built with bricks and coated with cement. These ponds are generally rectangular or square in shape, with areas ranging from 200 m^2 to 4 000 m^2, and depths of 1 to 1.5 m.

3.3.2 Stocking densities and feeding

Tilapia are stocked at about 20 000 to 40 000 fish/feddan (50 000 to 100 000 fish/ha) and fed commercial aquafeeds (25 to 35 percent CP). The majority of tilapia farmers (70 percent of the surveyed sample) use extruded pellets, while the rest (30 percent) use pelleted feed. Generally, 30 to 35 percent CP diets are used during the fingerling stages of production; these levels are reduced to 25 percent CP during grow-out. However, many farmers use 25 percent CP during the whole production cycle. While hand feeding twice per day is practiced (at 07.00 to 08.00 and 16.00 to 17.00 hours), the use of demand feeders is increasing; currently, about 60 percent of the intensive pond farmers use demand feeders. Between 10 to 14 feeders per ha are distributed at fixed distances along the sides of the ponds.

The feed conversion ratios (FCR) attained using pelleted feeds ranges between 1.3:1 and 1.9:1 for fingerlings, and between 1.2:1 and 1.5:1 for the grow-out production stage. In contrast, the FCR attained using extruded feeds range between 1:1 and 1.4:1 for fingerlings and between 1:1 and 1.2:1 for the grow-out stage.

3.3.3 Production cycle and yield

Farmers stock the 'young-of-the year' (2 to 5 g) in the ponds between May and June, and the fish grow to between 150 and 200 g over the next 5 to 7 months. Some farmers stock over-wintered tilapia (>30 g average weight) which grow to about 300 g to >400 g in 6 to 9 months. The total production at harvest ranges between 15 and 20 tonnes/ha, depending on the stocking density and the culture period. The methods used for harvesting tilapia in intensive pond systems are similar to those applied to semi-intensive pond culture.

3.4 Intensive tank culture

3.4.1 Tank construction and preparation

Intensive tank culture of tilapia in Egypt is growing, especially in the arid and semi-arid areas where freshwater or brackish water is limited. Tanks are generally rectangular and of smaller size to earthen ponds, and constructed mostly of concrete. Intensive culture in concrete green house units is gaining popularity in some areas in Behaira and Kafr El-Shaikh (Figure 8).

The size and shape of tilapia culture tanks are variable, and depend on the culture objectives. Fry and nursery tanks are generally small (<2 to 12 m^3), while production tanks typically are much larger. In a tilapia farm at Al-Nubaria, Behaira, an intensive tilapia farmer uses 600 m^3 concrete production tanks (20 x 30 x 1 m) with muddy bottoms. Irrigation and underground water are pumped directly into the ponds and tank effluents are used to irrigate agricultural crops.

3.4.2 Stocking density and feeding

About 80 percent of tilapia farmers using tanks in the study areas raise all-male Nile tilapia. Fish are stocked at densities that range between 25 and 100/m^3, depending on the initial stocking size. Tanks are also aerated with air compressors (½-1 horse power, depending on tank size and stocking density), paddle wheels (Figure 9), or water sprayed over the tank surface. Tank water is also partially replaced with fresh water when the water quality deteriorates. Unfortunately, information pertaining to aeration timing and

FIGURE 8
Tank culture of tilapia in Salhia, Sharkia Governorate, Egypt

COURTESY OF FAO/A.-F.-M. EL-SAYED.

FIGURE 9
Intensive tilapia pond in Barsiq fish farm, Behaira, Egypt being aerated with paddle wheels

COURTESY OF A.A. BALHASHER.

duration, water pumping, and costs, is limited; it is therefore difficult to generalize, since individual farmers adopt different procedures and practices based on their own experience.

The fish are generally fed with commercial extruded feeds (35 percent CP at the beginning, reduced to 25 percent CP during the fattening stages). A very small number of farmers use sinking pellets (25 to 30 percent CP). As the tanks are smaller than ponds, hand feeding is generally used. Feeding is typically 2 to 3 times per day (07.00 to 08.00, 12.00 to 13.00 and 17.00 to 18.00 hours). None of the surveyed farmers use demand feeders.

3.4.3 Production cycle and yield

Similar to the cage culture production systems, some tilapia farmers stock the 'young-of-the year' (2 to 5 g) in the tanks between May and June. The fish grow to about 200 g over a 5 to 7 month period. Other farmers stock over-wintered tilapia (30 to 60 g) which grow to between 300 g and >500 g over a 6 to 9 month period. The total production of tank-cultured tilapia at harvest ranges between 10 to 30 kg/m^3, depending on the stocking densities and culture periods. The tilapia are harvested by draining the water from the tanks, mainly by gravity. Generally, the tanks have a slight slope towards the draining points to facilitate drainage. Fish are harvested using scoop nets.

3.5 Cost-benefit analyses

The cost and benefits accruing to tilapia farms vary considerably and are dependent on the culture system adopted, the availability and costs of inputs, and the geographical region. For example, the cost of labour varies between regions.

The average costs and benefit-cost ratios (BCR) associated with tilapia culture in semi-intensive and intensive farming systems are summarized in Table 6. The lowest net revenues and BCR are obtained using semi-intensive systems. This is attributed to the fact that these systems are primarily used by small-scale farmers who do not have regular access to funding and production inputs. As a result, total costs, revenue and BCR are generally low; however, the practice is still very profitable to those farmers. In contrast, intensive tilapia culture is practiced by farmers who have much better access to funds and production inputs, and can thus operate systems with much higher operational capital and investment. Therefore, the net revenues and BCR in intensive tilapia culture are much higher. The total costs are much higher in tank culture than in cage and pond culture. Nevertheless, the BCR attributed to cage production is the highest, followed by pond and tank culture respectively.

TABLE 6
Cost-benefit analysis and average production costs and returns for tilapia culture in Egypt (US$/ha/production cycle) in 2009

Costs and returns	Semi-intensive system	Intensive systems		
		Ponds	600 m³ cages	Tanks (0.4 ha)
Variable costs				
Seeds	110	273	262	545
Feeds	3 636	10 000	13 630	16 364
Fertilizers	272	-	-	-
Labour (family and hired)	727	727	364	727
Miscellaneous costs	800	1 200	500	1 700
Total variable costs (TVC)	5 545	12 200	14 756	19 336
Fixed costs				
Depreciation	-	-	300	1 000
Land use cost	1 680	1 680	-	1 680
Total fixed costs (TFC)	1 680	1 680	300	2 680
Total costs (TC = TVC + TFC)	7 225	13 880	15 056	22 016
Total gross revenue (GR)	9 600	24 000	29 000	32 000
Net return (NR = GR – TC)	2 375	10 120	13 944	9 984
Benefit-cost ratio (BCR = GR/TC)	1.33	1.73	1.93	1.45

3.6 Characteristics of feed production

3.6.1 On-farm tilapia feed manufacturing

The use of farm-made feeds is extremely limited; none of the surveyed farmers reported them. However, some farmers in remote, rural areas, who produce the fish primarily for family subsistence, make their own tilapia feeds. These farmers generally depend on local feed ingredients, including agricultural by-products (wheat bran, corn bran, rice bran) and animal by-products (blood meal, offal, poultry by-product, etc.). El-Sayed (2007) reviewed the production processes used in farm-made feed production. Ingredients are sorted to remove spoiled or rotten parts and hard objects that may damage the manufacturing equipment. The feedstuffs are milled and mixed according to a formulation, water is added, and the compounded ingredients are cooked or steamed, or extruded without cooking. Moist strands are extruded using an electric meat mincer. The strands are sun dried, broken up and stored. In some cases, farmers do not extrude the diets; instead they feed the moist paste to the fish in the form of moist feed balls. Some small-scale farmers feed the dry feed mixture either by filling jute bags and suspending these in the water column or by broadcasting them over the water surface.

3.6.2 Commercial aquafeed industry in Egypt

The rapid expansion of aquaculture and in particular tilapia farming over the past two decades has been accompanied by an increasing demand for commercially manufactured aquafeeds. The gradual shift from extensive and semi-intensive tilapia culture to more intensive, feed-dependent systems has further increased the demand for commercial feeds. As a result, the aquafeed industry has witnessed a sharp increase in production capacity over the past few years. The number of aquafeed manufacturing mills has increased from only 5 mills producing about 20 000 tonnes per year in 1999 (El-Sayed, 1999), to 31 mills in 2009 (11 belong to the public sector and 20 owned by the private sector; Table 7), with a current production capacity of 420 000 tonnes/year (Mohamed F. Osman, GAFRD,

personal communication, 2010). These manufacturing plants produce both pelleted and extruded pellets for various marine and freshwater-cultured species (Table 8).

One of the most serious issues facing the aquafeed industry in Egypt is the poor handling and storage of the ingredients and the finished feeds. Stores in many feed mills lack the basic standards necessary for the storage and handling of materials to ensure feed freshness and minimize the exposure of the ingredients to contamination due to birds, rodents, insects and other environmental factors. Ingredients are often stored outdoors, on the ground, without any shading or protection (Figure 10). They are exposed to direct sunlight, heat, moisture, and the prevailing weather conditions. These poor storage conditions will certainly lead to the damaged ingredients and poor feed quality. Many farmers also store feed ingredients and purchased sacked feed on their pond dikes, often leaving them open to the prevailing weather conditions for several weeks – during which time the feed quality will almost certainly deteriorate.

In contrast, many private feed mills have excellent handling, storage and transportation facilities, and comply with the Code of Practice for Good Animal Feeding (FAO, 1998). However, the feed prices from these mills are generally higher than from the government-run feed mills.

FIGURE 10
An example of poor feed ingredient storage

Courtesy of FAO/A.-F.M. El-Sayed.

TABLE 7
Number of aquafeed mills and total fish feed production in Egypt in 1999 and 2009

Feed mills	1999	2009
Governmental/Public sector	5	11
Private	-	20
Total feed production (tonnes)	20 000	420 000

Source: El-Sayed (1999); K. El-Sharkawi, personal communication, 2010; M.F. Osman, GAFRD, personal communication, 2009.

TABLE 8
Commercially available complete aquafeeds in Egypt

Commercial product	Company	Examples of prices (US$/tonne)
Extruded and pelleted feeds for tilapia, carp, mullets and marine fish	Zoocontrol	500–650 (based on protein contents and type of feeds)
Pelleted pellets for tilapia, carp, and mullets	Barsiq feed mill (GAFRD)	360–450 (sinking pellets)
Pelleted pellets for tilapia, carps, mullets and seabream and seabass	Manzalla feed mill (GAFRD)	360–450 (sinking pellets)
Floating (extruded) tilapia feeds (1–5 mm) (25–40% CP), sinking tilapia feed (2–5 mm), marine fish feeds, aquarium fish feeds	JOE Trade	520 (25% CP; floating) 565 (30% CP; floating)

Source: Field survey (2010); personal contacts with the manufacturers.

3.6.3 Tilapia feed industry

Approximately 280 000 tonnes (65 percent) of the aquafeeds produced in Egypt are used for tilapia farming. Tilapia feeds are produced primarily in the form of conventional pelleted (sinking) pellets. Pellet sizes range between 2 and 5 mm, and the feed is mostly used in semiintensive culture systems – monoculture and polyculture systems with mullets and carps. A significant proportion of pelleted feeds is used in intensive, monoculture production systems.

Extruded (expanded, or floating) aquafeed technology was introduced into Egypt in the mid-1990s. Since 2001, a number of commercial, private feed manufacturers have added production lines for extruded feed production to complement their traditional production lines. The market demand for extruded feed is increasing, despite the significantly higher prices. Tilapia farmers prefer this type of feed because it is better digested, converted and assimilated by the fish (El-Sayed, 2007). Indeed, approximately 40 percent of surveyed tilapia farmers use extruded feeds. Feed conversion ratios (FCR) for pelleted Nile tilapia feeds range from 1.5:1 to 2.5:1, while the FCR associated with extruded feeds range from 1.1:1 to 2:1, depending on fish size and culture system (Figure 11). The formulation and proximal composition of typical 25 percent CP extruded and pelleted, and 35 percent CP pelleted feeds are presented in Table 9.

TABLE 9

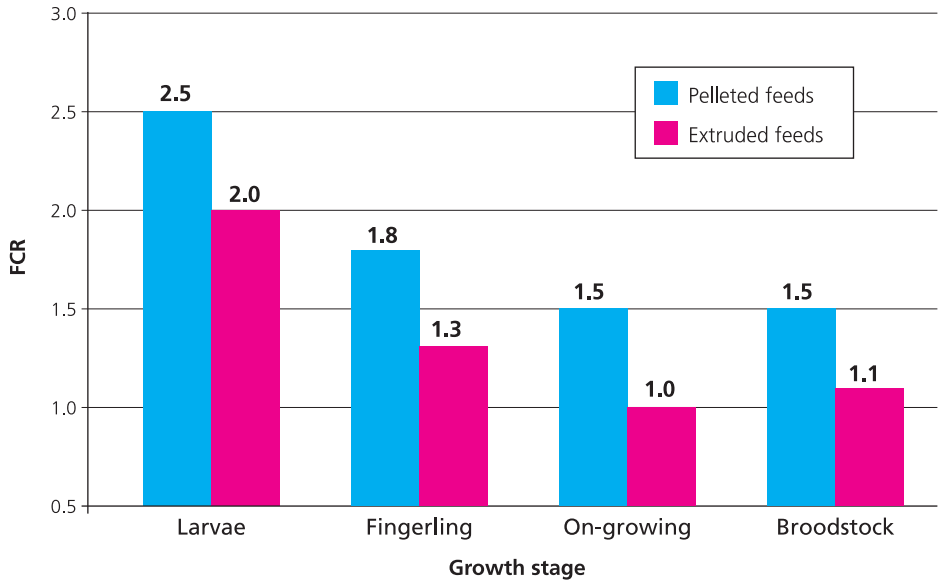
Formulation and proximate composition of commercial tilapia diets in Egypt

Feed type	25% CP diet		35% CP diet
	Pelleted (GAFRD; government mill)	Extruded (private sector)	Pelleted (GAFRD; government mill)
Ingredients (%)			
Soybean meal (44% CP)	37.5	19.0	40.0
Fishmeal (sardine, 60% CP)	6.0	9.0	22.0
Corn gluten	-	5.6	
Yellow corn	22.5	30.0	12.0
Wheat bran	-	24.0	-
Rice bran	23.0	11.0	19.1
Oil	3.0	1.0	3.0
Calcium carbonate	4.7	-	3.075
Binder	2.5	-	-
Table salt	0.5	-	0.5
Vitamin mixture	0.3	0.4**	0.3
Antioxidant	0.025	-	0.025
Proximate composition (% dry matter basis)			
Crude protein	25.0	25.0	35.0
Crude lipid*	8.8	7.5	8.4
Crude fibre*	5.7	5.4	6.3
Ash*	4.3	3.9	3.9
NFE*	56.2	58.2	46.4

Notes: *calculated by the author, based on the chemical composition of the ingredients; **vitamin and mineral pre-mix.
Source: GAFRD (General Authority for Fisheries Resources Development, Egypt).

The average FCR values presented in Figure 11 that are attributed to the different growth stages of Nile tilapia fed pelleted and extruded feeds were based on the values provided by the farmers, as well as published papers and reports. It is clear that the FCR of larval and fingerling stages are higher than those of grow-out and broodstock fish. This is primarily attributed to the fact that aquafeed manufacturers do not produce specialist larval and fingerling feeds (<1 mm). Instead, most of the farmers crush the feeds that are formulated for grow-out (2–3 mm) into pieces before feeding them to the fry and fingerlings. This practice leads to feed waste, resulting in higher FCR (lower feed utilization efficiency) in these early growth stages.

FIGURE 11
Average feed conversion ratios (FCR) of Nile tilapia fed commercial diets



Sources: Field survey (2010); El-Sayed (2004, 2006, 2007); Osman & Sadek (2004).

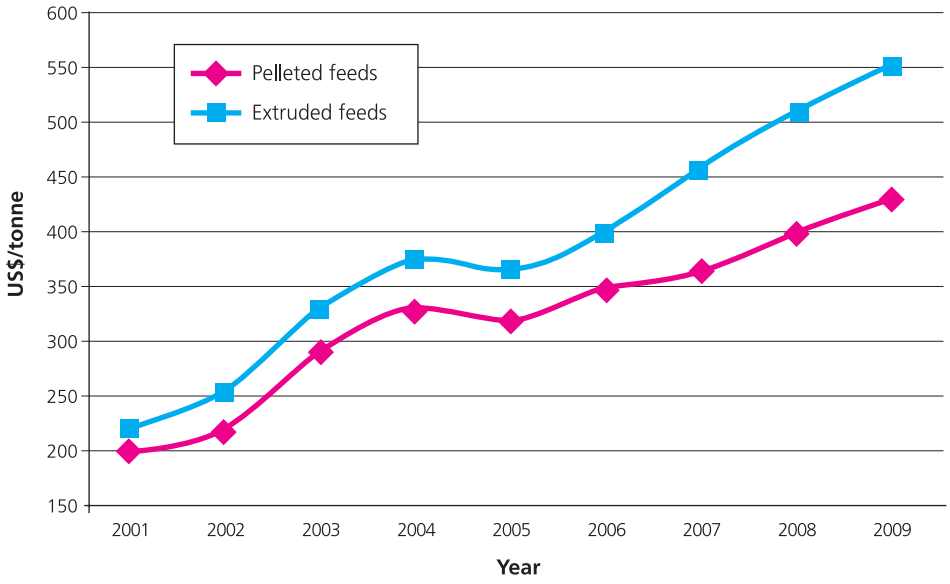
Commercially produced tilapia feeds are usually packed in 25 to 50 kg woven polypropylene bags (Figure 12). The bags are closed either manually with a string or mechanically heatsealed. Feeds are generally stored in shaded well aerated stores. However, some factories (especially government mills) lack appropriate storage facilities for their ingredients and finished feeds.

The prices for pelleted tilapia feeds in Egypt has doubled over the past decade, increasing from ~US$200/tonne (25 percent CP) in 2001 to US$400–450/tonne in 2009 (Figure 13). Similarly, the price of extruded feeds has increased 2.5-fold, from US$220/tonne in 2001 to about US$550/tonne and US$650/tonne (25 and 32 percent CP, respectively) in 2009. The increasing prices of both pelleted and extruded tilapia feeds have primarily been caused to increases in the prices of feed ingredients, especially those that are imported, such as fishmeal, soybean meal, corn, wheat bran and oils, as detailed in Section 3.7.2. In addition, increase in prices for extruded feeds is related to the high investment costs associated with the installation and operation of the specialist extrusion machinery.

FIGURE 12
Tilapia feed (25% CP) packed in 25 and 50 kg polypropylene bags

COURTESY OF FAO/A.-F.M. EL-SAYED.

FIGURE 13
Price of extruded and pelleted tilapia feeds (25% CP) between 2001 and 2009



Sources: Field survey (2010); El-Sayed (2007); K. El-Sharkawi, JOE Trade, personal communication, 2010.

3.7 Major feed ingredients

3.7.1 Locally produced ingredients

The estimated quantities of major feed ingredients that are currently used for the animal feed and aquafeed industries in Egypt are presented in Table 10. Most of these, especially the energy sources, are used for (terrestrial) animal feed production. Since 2004, the production of some oil seeds (linseed, cottonseed and soybean) has been decreasing.

TABLE 10
Production of major feed ingredients (thousand tonnes) in Egypt between 2004 and 2008

Item	International feed number (IFN)	2004	2005	2006	2007	2008
Cereals						
Barley	4-00-549	163	163	154	178	149
Maize	4-02-935	6 352	6 125	6 755	6 877	6 544
Rice	4-03-943	6 352	6 125	6 755	6 877	7 253
Rye	4-04-047	30	40	60	44	44
Sorghum	4-04-444	864	853	887	844	844
Wheat	5-05-211	7 178	8 141	8 274	7 379	7 977
Oilseeds						
Groundnuts, with shell	-	191	200	184	218	209
Linseed	-	30	28	10	12	12
Cottonseed	5-01-619	446	335	335	335	335
Sesame seed	5-04-220	29	37	42	42	37
Soybean	5-04-597	43	51	23	26	29
Sunflower	5-09-340	12	34	38	29	21
Oils						
Cottonseed oil	4-20-836	51	59	49	48	38
Linseed oil	4-14-502	10	14	9	4	12
Soybean oil	4-07-983	46	100	96	150	220
Sunflower oil	4-20-833	8	9	8	8	7

Source: FAO (2010).

3.7.2 Imported feed ingredients

Between 50 and 75 percent of feed ingredients that are used in aquafeed production in Egypt are imported. As a result, their prices have been increasing substantially over the past few years (Table 11). For example, between 2003 and 2007, the quantities of the major imported feed ingredients increased from 7 696 000 tonnes to 13 028 000 tonnes, equating to a 69 percent increase in imports. Similarly, the increase in the unit prices paid ranged between 7 and 78 percent. Thus, for the aquafeed industry to remain competitive, the Egyptian feed manufacturers need to source ingredients on the international markets at competitive prices.

TABLE 11
Imported quantities and prices of feed ingredients in 2003 and 2007

Ingredient	International feed number (IFN)	2003		2007		Increase in price (%)
		Thousand tonnes	US$/tonne	Thousand tonnes	US$/tonne	
Wheat	4-05-268	4 057	149	5 911	265	78
Maize	4-02-935	4 053	130	4 474	210	62
Soybean seed	5-04-597	332	268	1 136	376	40
Soybean cake	5-04-612	826	238	1 010	291	22
Sunflower oil	4-20-833	123	570	151	741	30
Gluten feed and meal	5-28-242	54	299	81	472	58
Soybean oil	4-07-983	107	530	96	728	37
Meat meal	5-09-323	137	325	87	350	7
Total		**9 796**		**13 028**		

Source: FAO (2010).

The estimated volume and value of major feed ingredients that are currently used by the aquafeed manufacturing industry for tilapia feed production is presented in Table 12. About 70 percent of these ingredients are imported, most notably the protein sources. As a result, the prices of aquafeeds are relatively high compared to other animal feeds (El-Sayed, 2007).

TABLE 12

Estimated quantities and values of the major feed ingredients used in total aquafeed and tilapia feed production in Egypt in 2008

Ingredient	International feed number (IFN)	Origin	Total aquafeeds		Tilapia feeds	
			Quantity (tonne)	Value (thousand US$)	Quantity (tonne)	Value (thousand US$)
Fishmeal	5-02-000	Imported	20 000	48 000	13 000	31 200
Meat meal	5-00-385	Imported	10 000	3 410	6 000	2 217
Soybean meal	5-04-612	Imported	100 000	27 645	64 750	17 969
Yellow corn	4-02-935	Imported	160 000	29 400	106 000	19 110
Rice bran	4-03-928	Local	40 000	75 000	26 000	48 750
Wheat bran	4-05-190	Local	80 000	60 000	52 000	39 000
Corn gluten meal	5-28-242	Imported	15 000	6 405	9 750	4 163
Soybean oil	4-07-983	Local	250	182	163	118
Vitamin and mineral premix		Local	150	600	95	390
Total			**375 400**	**247 232**	**278 758**	**162 917**

Source: Calculated by the author, based on the percentage of each ingredient in the feeds.

3.7.3 The contribution of pelleted feeds to tilapia production

Egypt currently produces about 420 000 tonnes of aquafeeds per annum, the majority of which is in the form of sinking pellets (25 percent CP). Approximately 280 000 tonnes of this feed (67 percent) is used in tilapia production. The average current feed conversion ratio (FCR) for tilapia using these feeds is in the region of 1.5:1; thus the amount of tilapia feed would probably produce about 187 000 tonnes of tilapia. In 2008, this level of production would represent 48 percent of the total production of farmed tilapia (386 186 tonnes). However, this figure is dependent on an estimated FCR, and thus may be higher or lower than the real value. Notably, it is difficult to determine accurate FCR when both natural food (produced through fertilization) and supplemental feeds are used in the same production cycle. The remaining tilapia production can be attributed to pond fertilization and natural feeds.

Evidently natural feeds, produced through pond fertilization, still play a key role as a nutritional input in tilapia aquaculture in Egypt. Dependence on pond fertilization is anticipated to continue, at least in the short term. This is simply due to the fact that it is easier and more convenient for small-scale Egyptian pond farmers to adopt semi-intensive culture systems.

In contrast, intensive tilapia culture requires high capital investment, high operational costs, and professional management. It would be very difficult for small-scale farmers to afford these costs. However, the shortage of freshwater and increasing competition for water resources from other sectors, such as agriculture and urbanization, suggests that there may be a gradual shift from the traditional semi-intensive to more intensive production systems. The limitation of potential aquaculture sites will also impose pressure on the industry to shift towards intensification. If this happens, the aquaculture sector will probably become dominated by large-scale producers who have access to the funding and level of technological inputs necessary.

4. PROBLEMS AND CONSTRAINTS OF TILAPIA FEEDS AND FEEDING

The following problems and constraints were reported by the surveyed farmers:

- Feed prices: all surveyed farmers complained about the high prices of both pelleted and extruded feeds.
- Variations in feed quality: approximately 40 percent of the farmers reported that they sometimes purchase poor quality feeds as they cannot differentiate between good and bad feeds.
- The increase in the prices of feed ingredients, particularly imported ingredients such as fishmeal, soybean, corn, oils and additives has led to parallel increases in feed prices.
- The unavailability of small sized pellets (<1 mm diameter) for larval and fingerling stages; most of the aquafeed mills in Egypt do not currently have the production technology to produce these.
- The high custom tariffs and taxes on imported ingredients and manufacturing equipment have contributed to rising feed costs.
- There are concerns that increasing competition for raw materials between the aquafeed and the animal feed industries may influence their price.
- One of the most serious problems facing the tilapia feed industry in Egypt is the poor handling and storage facilities for ingredients and finished feeds.
- Small-scale tilapia farmers lack access to finance, which makes them vulnerable to exploitation by the suppliers of the feeds and fertilizers. Many farmers purchase their feed during the production cycle but payment is delayed until after the fish are harvested and sold. As a result, they are generally supplied at higher prices.
- There is a lack of extension services to advise tilapia farmers on pond fertilization, feed formulation, manufacture and feeding practices.
- Small-scale, semi-intensive tilapia farmers are generally unaware of the appropriate fertilization strategies and the techniques that should be adopted to optimise pond productivity.
- There is limited applied research on tilapia nutrition, feeding and fertilization strategies.

5. RECOMMENDATIONS

It is clear from the foregoing discussion that extensive efforts should be made to improve feed and fertilization management practices. The following recommendations have been suggested by tilapia farmers, aquafeed manufacturers and researchers, and are designed to solve these issues:

- A thorough survey of the available conventional and unconventional feed resources in the country should be undertaken. An evaluation to establish their availability, accessibility, price and nutritional value for cultured fish should be conducted. The chemical composition of these sources should be identified.
- Consideration should be given to optimizing feed and fertilization strategies in semi-intensive culture systems. Pond preparation, fertilization rates and intervals, soil and water analyses, and the timing for initiating artificial feed supplementation are prime issues that need to be addressed.
- Reducing, or at least stabilizing, the prices of both feed ingredients and finished feeds, through reducing customs tariffs on feed ingredients and other production inputs, monitoring the profit margins of feed producers, followed by governmental intervention when necessary.
- Consideration should be given to the identification of novel dietary sources that can partially or totally replace standard protein and energy sources in fish feeds.
- Improving the quality of aquafeeds through improved handling, transportation, storage, processing and the removal of anti-nutritional factors (if present). The continuous monitoring of feed producers, suppliers and ingredients importers

by governmental authorities is necessary to assure that they comply with the international quality control standards, such as Hazard Analysis and Critical Control Points (HACCP) and the Code of Practice for Good Animal Feeding (FAO, 1998).

- Research efforts should focus on feedstuffs that have low digestibility and high fibre contents, such as sugar cane bagasse, reeds and water hyacinths, which are available in large amounts throughout the country. The quality of these potential ingredients can be improved by processing, such as heating, silaging and composting. In addition to their use as feed ingredients, they can be composted and used as fertilizers in fish ponds.
- The government should support fish farmers to access the necessary loans at appropriate lending rates to develop their businesses.
- There should be routine government inspections and monitoring of both feed ingredients used in aquafeed manufacturing and commercial aquafeed mills. This should be designed to ensure that that production procedures, packaging, handling, transportation and storage comply with the quality control standards issued by the government. Inspections should include, but should not necessarily be restricted to:
    - The analysis of feed ingredients for freshness, cleanliness and exposure to contamination due to birds, rodents, insects and environmental stressors such as heat, sun, rain, etc.
    - Finished feed distributed in the market or on-farm should be sampled and analyzed for protein, lipids, fibre and moisture contents and compared with the levels described on the labels. The presence of hazardous substances/additives, such as fungi, medicinal substances, hormones, pesticides, etc. should be checked. Appropriate methods should be adopted to eliminate such hazards.
    - Routine inspections on the cleanliness of feed manufacturing premises and equipment.
- Legislation and regulations should be issued by the government to guarantee the quality and safety of aquafeeds. These should define the responsibilities and designate authority with respect to the activities required, establish basic procedures for enforcement, and provide standards, guidelines and recommendations for the industrial manufacturing of aquafeeds. Legislation and regulations concerning the manufacture, handling, storage and use of aquafeeds should be coherent and complementary parts of the overall national feed/food legislation. The government should also undertake periodic reviews of the food/feed legislation to ensure its coherency, and to reduce/eliminate any overlapping, redundant and conflicting jurisdictions.

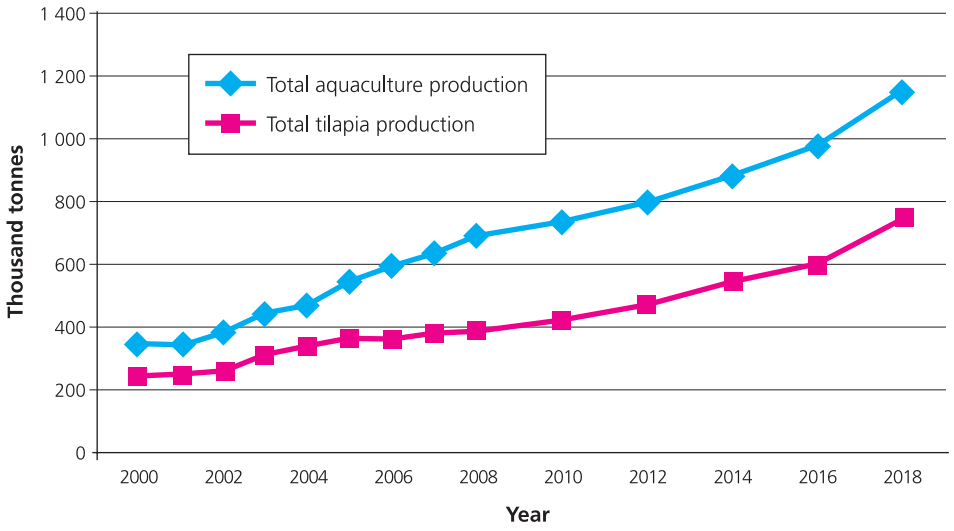
In addition to these recommendations, the Code of Practice for Good Animal Feeding (FAO, 1998) contains valuable information related to good feed manufacturing and feeding practices.

6. FUTURE PERSPECTIVES

As shown in this report, the production of farmed Nile tilapia in Egypt increased substantially between 1990 and 2008. It is very likely that aquaculture in general, and tilapia culture in particular, will continue to grow. However, suitable and available sites for tilapia culture development are being heavily exploited, leaving little room for future expansion. Therefore, tilapia culture expansion will depend on the optimum use of resources. This will require a gradual shift from the existing extensive and semi-intensive practices to more intensive production systems. This approach will inherently increase the dependence on manufactured feeds, thereby reducing the demand for organic and inorganic fertilizers.

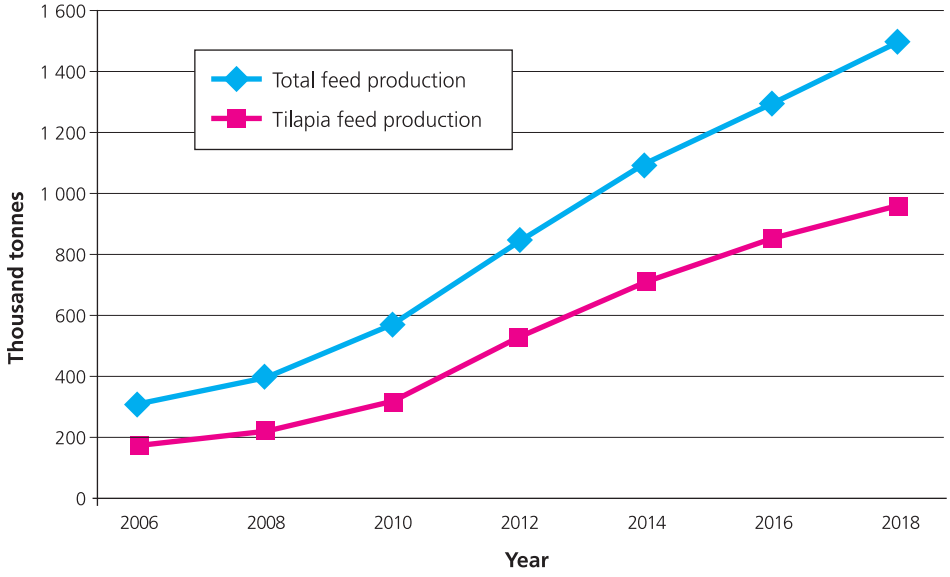
The aquaculture target of Egypt is to produce about 1 000 000 to 1 200 000 tonnes/year by 2018 (MALR, 2007) (Figure 14). This means that aquafeed production is expected to increase to about 1.5 to 1.7 million tonnes/year (Figure 15), assuming an FCR of between 1.2:1 and 1.5:1. The current contribution of tilapia production to total aquaculture production (56 percent) is expected to increase to 60 to 70 percent (due to intensification). Therefore, commercial tilapia feed production is expected to reach about 700 000 to 900 000 tonnes/year by 2018 (Figure 15).

FIGURE 14
Projected total aquaculture and tilapia production in Egypt until 2018



Source: GAFRD (2009); MALR (2007).

FIGURE 15
Projected total aquafeed and tilapia feed production in Egypt until 2018



Note: Tilapia feed production for this figure was calculated by the author based on the contribution of tilapia to total aquaculture production.

Sources: El-Sayed (2007); M.F. Osman, GAFRD, personal communication, 2009.

It is expected that there will be sharp competition for ingredients by the aquafeed and animal feed industries. Accordingly, the prices of feed ingredients in general, and imported ingredients in particular, will increase. Small-scale tilapia farmers are likely to be the most seriously affected groups. It is incumbent upon the government to develop action plans to deal with the potential crisis in the aquafeed industry. Special attention will have to be paid to small-scale tilapia farmers who might be enforced to abandon their traditional semi-intensive farming systems to the high input-demanding intensive system.

It is also expected that feed manufacturers will make greater and better use of non-conventional feed resources that are readily available and accessible in Egypt. Those manufacturers will also add production lines in their feed mills for larval and fingerling feed production. Fish nutrition researchers and specialists will also have to conduct more research on the use of non-conventional feed resources. It also expected that the government will impose more restrictions on quality control and inspection standards over feed ingredients, processed feed and produced fish.

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On-farm feed management practices for Nile tilapia *(Oreochromis niloticus)* in the Philippines

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ABSTRACT

The contribution of the Philippines to tilapia production in Asia has increased steadily in the past five years as it addresses hunger and poverty alleviation in the region. Commercial tilapia aquaculture in the Philippines has improved as farmers have become aware of the importance of adopting innovative husbandry technologies. These include the use of intensive culture, using novel feed ingredients, improving the quality of industrial aquafeeds, adopting cost-effective feeding strategies and efficient pond fertilization methods, and culturing improved genetic strains. A case study was conducted to: a) assess current tilapia feed management practices; b) determine recent nutrition-based innovations that include the use of alternative feed ingredients, the adoption of nutritionally complete commercial tilapia feeds, and improvements to feed management practices; and c) evaluate these factors in terms of improved production efficiencies. Thirty-two farmers from selected tilapia cage hatcheries, pond hatcheries, grow-out cages and ponds in Regions III and IV-A (known major tilapia producing regions in the Philippines) were interviewed. The issues addressed included their farm management practices, with particular focus on tilapia feed preferences; quality, procurement and storage methods; and feeding strategies. Their responses were collated and analysed in the context of information simultaneously gathered from the scientific literature, popular publications and relevant websites. The results from the case study highlight the importance of farmers being trained and remaining well-informed about recent improvements in feed technologies and the use of efficient cost-saving feeding strategies to optimize the production of seed and marketable tilapia. Recommendations on how to increase tilapia production through improved feed and feed management practices are described. Finally, recommendations for local regulatory agencies to implement aquafeed quality and nutrient standards are provided.

1. BACKGROUND

1.1 Nile tilapia farming in the Philippines

Although native to Africa and the Middle East, the tilapia is now a globally cultured freshwater fish that is currently produced and consumed in nearly 100 countries worldwide (Fitzsimmons, 2000). A large portion of world tilapia production comes from Asia. The first known Asian introduction of the species was in 1939 when the Mozambique tilapia (*Oreochromis mossambicus*) was introduced into Indonesia. In 1950, the species found its way to the Philippines, where it was promoted as a potential species for subsistence farming. However, when local culturists experienced problems in growing Mozambique tilapia due to its perceived inferior production traits, interest in commercial tilapia culture waned. Profitable tilapia farming in the Philippines began only in the 1970s, when Nile tilapia (*Oreochromis niloticus*) was introduced for pond and cage culture. Although production was initially in ponds, local cage farming techniques were readily developed, and the Philippines became a pioneer in Asia for Nile tilapia cage culture in lakes and reservoirs (Guerrero, 2002; BFAR-PHILMINAQ, 2007).

Since 1980, hybrid red tilapias (*Oreochromis* spp.) have also been farmed in the Philippines. However, the majority of Philippine tilapia production is still based on *Oreochromis niloticus.* Production is primarily restricted to: a) traditional extensive culture in earthen ponds; b) semi-intensive farming in cages, pens and ponds; and c) intensive culture in cages, ponds and tanks (Figures 1.1–1.4). The differences between the three production systems are the level of inputs and the intensity of production (PHILMINAQ, 2007; Eguia and Romana-Eguia, 2007; Lim and Webster, 2006). Under extensive culture, tilapia are stocked at low densities in fertilized ponds where the fish are not fed, and depend on the natural productivity of the system to supply their food and nutrition. Minimal labour inputs, little water exchange and no artificial aeration are applied, and thus low yields are attained. In semi-intensive systems, fish are stocked at higher densities and are dependent on natural feeds and supplemental feeds such as cereals, fishery by-products and/or formulated feeds. Water exchange under semi-intensive culture conditions is moderate, and aeration is provided partially or continuously. Finally, in intensive systems, tilapias are stocked at very high densities, and are totally dependent on formulated feeds to supply their nutritional requirements. Typically, water exchange rates are higher than in the semi-intensive and extensive systems; higher labour inputs and continuous aeration need to be provided. Table 1 provides a summary of the specific inputs that are required to operate each type of culture system, and outlines nutrition-related inputs (feeds and fertilizers) and the feed and water quality management systems that are required.

FIGURE 1.1
Earthen pond-based tilapia culture in the Philippines

COURTESY OF E. ROXAS.

FIGURE 1.2
Tilapia cages in Taal Lake, Batangas, Philippines

Source: http://pcij.org/blog/wp-content/uploads/2008/06/taal-lake.jpg

FIGURE 1.3
Tilapia pen culture in Laguna Lake, Philippines

Source: SEAFDEC/AQD (2009).

FIGURE 1.4
Concrete tanks for use in breeding and small-scale tilapia farming

COURTESY OF FAO/M.R.R. ROMANA-EGUIA

TABLE 1
Tilapia production systems in the Philippines

Parameters	Extensive		Semi-intensive		Intensive	
	Ponds	Cages	Ponds	Cages	Ponds	Tanks
Culture period (months)	4–5	4–6	4–6/7–8*	4–5	4–5	4–5
Size at stocking (g)	10–20	10–20	10–20/50*	10–20	10–20	10–20
Stocking density	3 000–5 000/ha	15–25/m^3	10 000–50 000/ ha/ 20 000/ha*	50–250/m^3	50 000–100 000/ ha	100–200/m^3
Water management	50% water exchange after 2 months	None	Frequent water change	None	5–10% water exchange daily	Flow-through
Fertilization	2 weeks after pond preparation	None	Applied in the first two months	None	Only at stocking	None
Feeding	None	Natural food + supplemental feed**	Natural food + supplemental feed**/ natural food + commercial feed	Commercial feed	Commercial feed	Commercial feed
Use of aerator	No	No	Optional	Optional	Yes	Yes
Size at harvest (g)	100–200	250–300	150–200/ 750–800*	150–250	250	>300
Survival rate (%)	80–100	70–90	60–85/60*	60	60	70–85
Yield	300–800 kg/ha	2.7–7.0 kg/m^3	1 000–3 000kg/ ha/1 000 kg/ha*	4–40 kg/m^3	7 000–15 000 kg/ha	20–50 kg/m^3

Notes: * Data from the San Antonio Aqua Fisheries Inc. (SAAFI), a local company engaged in the production and processing of exportable-size tilapia; **supplemental feed here refers to single feed ingredients, e.g. rice bran, bakery wastes (bread crumbs), kitchen scraps or formulated feeds.
Source: Sumagaysay-Chavoso (2007); Eguia and Romana-Eguia (2007); Guerrero (2002); Aldon (1998); Field survey (2010).

1.2 Production trends

In 2008, global production of Nile tilapia was 2.1 million tonnes – more than double that recorded in 2000 (FAO, 2012). This unprecedented increase in production may expand further, as more countries start to culture the species. In addition, tilapia producers have been intensifying their farming practices, thus contributing to higher farm yields (Lim, Webster and Li, 2006). The motivation to increase yields comes with increased consumer demand for inexpensive yet healthy sources of animal protein. In this regard, Nile tilapia, especially when organically farmed, provides a healthy, cheap product for health conscious consumers.

In 2008, Asian Nile tilapia production was recorded at 1 559 151 tonnes, equating to 76 percent of the world's tilapia production (2 061 816 tonnes). The largest producer country was China which produced 832 698 tonnes, followed by Indonesia at 291 038 tonnes, Thailand at 217 246 tonnes, and the Philippines at 188 103 tonnes (FAO, 2012). In 2008, local data from the Philippine Bureau of Fisheries and Aquatic Resources (BFAR) registered a total production of 257 133 tonnes of tilapia (Table 2; BFAR, 2008), representing a production volume that is approximately 69 000 tonnes more than that reported by the FAO. However, the BFAR report includes the production of all the known commercial tilapia species. Among the different regions of the Philippines, production ranged between 269 tonnes and 124 020 tonnes. Production was widely dispersed and derived from a range of culture environments and systems, including freshwater and brackishwater ponds, cages and pens, small farm reservoirs, rice-fish integrated systems and, although negligible, even marine fish cages (Table 2). Figure 2 shows the locations of the various regions.

TABLE 2

Aquaculture production (tonnes) of tilapias in the Philippines, 2008

Region	Total	Brackishwater			Freshwater			Small reservoir	Rice-fish culture	Brackishwater fish cage
		Fish pond	Fish cage	Fish pen	Fish pond	Fish cage	Fish pen			
NCR	501	132				369				
CAR	3 195				1 667	1 528				
I	6 915	1 183	52	58	5 543	49		30		
II	11 261	2 844	119		7 242	977		79		
III	124 020	6 801	2		117 124	6		87		
IV-A	81 255	44			1 577	67 637	11 997			
IV-B	575				575					
V	10 835	135			1 663	9 037				
VI	1 211	793			417					
VII	269	123			132	10		5		0.10
VIII	372	57		2	199	82	33			
IX	1 931	1 837			95					
X	1 454	401			1 053					
XI	913	169			721	3	20			
XII	8 236	232			579	1 765	5 659			
CARAGA	379	57	2	8	204	108				
ARMM	3 810	151			73	177	3 409			
TOTAL	**257 133**	**14 957**	**175**	**68**	**138 862**	**81 748**	**21 120**	**202**	**1**	**0.10**

Source: BFAR (2008).

FIGURE 2

Map of the Philippines showing the different regions

REGIONS IN THE PHILIPPINES

NCR- National Capital Region
CAR - Cordillera Administrative Region
Region I- Ilocos Region
Region II- Cagayan Valley
Region III - Central Luzon
Region IV A - Calabarzon
Region IV-B - Mimaropa
Region V - Bicol Region
Region VI - Western Visayas
Region VII- Central Visayas
Region VIII - Eastern Visayas
Region IX - Zamboanga Peninsula
Region X - Northern Mindanao
Region XI - Davao Region
Region XII - Soccksargen
Caraga - Caraga Region
ARMM - Autonomous Region in Muslim Mindanao

Source: http://mapsof.net/uploads/static-maps/philippines_regions_and provinces.png and http://en.wikipedia.org/wiki/Regions_of_the_Philippines

1.3 Technological developments in the Philippines

The increase in Nile tilapia production over the past decade (FAO, 2012), can be attributed to various technological interventions. These include hormonal/genetic manipulation and strain improvements, and refinements to feed, water and culture systems and their management. Since 1987, national and regional research institutions have been involved in selective breeding programmes to improve culture strains and, since 2000, these improved strains have been commercialized. These strains include the FaST (Freshwater Aquaculture Center Selected Tilapia), the SEAFDEC selected strain, the GIFT (Genetically Improved Farmed Tilapia) as well as other GIFT-derived strains such as the GST (Genomar Supreme Tilapia) of GenoMar and the GET-Excel tilapia being promoted by the BFAR (Eguia and Romana-Eguia, 2007; ADB, 2005a; Romana-Eguia *et al.*, 2004). A Tilapia Science Center was established in the Science City of Munoz, Nueva Ecija, where most of the tilapia selective breeding research projects and institutions are found. Realizing the importance of genetic improvement, one local feed company (B-MEG) has even developed its own improved strain (BEST 200) that they promote to fish farmer clients who use their commercial diets (B-MEG website: www.b-meg.com).

The rationale of using improved stocks is for the farmers to rear fish that have the genetic potential to: (a) grow and breed well; and (b) tolerate and/or survive sub-optimal culture conditions, environmental stressors (such as fluctuating salinity and water temperature levels due to climatic change), and diseases (Ponzoni, 2006; Eknath and Hulata, 2009). Although most of the improved stocks were primarily developed to promote better growth, farmers also require stocks to possess other production traits, including optimal fillet yield and carcass quality, late onset of sexual maturity, high fecundity, efficient feed utilization, and stress and disease tolerance (Siriwardena, 2007). Since the current trend to boost national production is to culture tilapia in brackishwater ponds that were originally devoted to milkfish and marine shrimp culture, two BFAR regional stations have produced and are currently field testing hybrids referred to as a) 'Molobicus' (Nile x Mozambique tilapia hybrids) and b) 'BEST' (Brackishwater Enhanced Selected Tilapia; no relation to the BEST 200 strain of B-MEG) strain tilapia, which are stocks suited for saline culture. Recently there were plans to develop improved Nile tilapia strains through genetic manipulation methods (e.g. transgenesis, triploidy); however the perceived risks associated with developing genetically manipulated organisms (GMO) make these approaches unacceptable in Philippine commercial aquaculture. Fortunately, the development of genetically manipulated tilapia has not been approved by local funding agencies and will not be pursued. Finally, it has been noted that the development of improved strains has been undertaken by agencies/groups that have access to technology and funds; consequently, the genetic strains they produce are mostly controlled by and benefit large businesses/private agencies, rather than marginalized farmers and smaller aquaculturists (Bartley *et al.*, 2009) Despite this, the initiatives to develop genetically improved strains continue, and in this regard, the WorldFish has transferred some of their GIFT broodstock from the Philippines to Penang, Malaysia to continue their selective breeding work.

In addition to the traditional stock selection techniques, sex reversal and advanced stock manipulation techniques (YY super male production; Mair, 2002) have also been developed for the production of mono-sex tilapia. Moreover, field-tested feeds, tilapia phase diets (feeds for the various tilapia growth stages), improved health management strategies, and a variety of hatchery and grow-out system innovations have also improved production characteristics.

1.4 Recent on-farm innovations

Traditionally, Nile tilapia has been cultured in freshwater. Production is divided between freshwater ponds, (54 percent), freshwater cages (32 percent), and freshwater

pens (8 percent), with brackishwater ponds contributing just 6 percent of production (BFAR, 2008). Freshwater and brackishwater pond culture are practiced in Region III, while freshwater cage and pen farming is primarily restricted to Region IV-A (Asian Development Bank, 2005b; BFAR-PHILMINAQ, 2007). In addition, many of the tilapia hatcheries are also concentrated in Regions III and IV-A, and these areas are now the major production areas. The Tilapia Science Center, comprising the GIFT Foundation International Inc., FAC-CLSU, PhilFishgen, BFAR-NFFTC and Genomar, is located in Region III.

Improved seed stocks are sold at premium prices and are presumed to require lower feed inputs than conventional strains. Despite the higher seed stock costs, the use of genetically improved tilapia strains increases farm profitability. Based on local farm interviews, 56.3 percent of the farmers, the majority from Region III, use genetically improved seed stock for grow-out, and 62.5 percent use improved broodstock.

A recent innovation is the culture of saline-acclimated Nile tilapia in brackishwater ponds that were originally designed for milkfish and shrimp farming. As a euryhaline species, sea cage farming has also been considered however, to date this technology remains to be proven. In the event that tilapia mariculture is developed, it will most likely be confined to the culture of Nile tilapia hybrids crossed with more salt-tolerant species such as the Mozambique (*O. mossambicus*) and Zanzibar (*O. urolepis hornorum*) tilapias. Brackishwater tilapia culture was initiated when the shrimp industry encountered disease problems that significantly affected marine shrimp production. Currently, farmers are using ordinary Nile tilapia seed stock acclimatized to 17 ppt; however, once saline tolerant strains from BFAR are disseminated commercially, it is likely that production from brackishwater ponds will increase (Tayamen *et al.*, 2004).

In recent years many farmers have started to intensify their farming operations. The rationale for intensifying the farming systems comes with the realization that the water and land resources that are available for aquaculture development are finite, and therefore their use has to be maximized (Rana, Siriwardena and Hasan, 2009). In this regard, some farmers have shifted production from extensive and semi-intensive culture to intensive culture. This shift in intensification requires increased feed inputs. Intensive culture technologies are primarily applied to pond operations in Pampanga, and cage operations in Taal Lake, Batangas. In intensive cage culture operations, farmers use supplemental feeds (agricultural by-products, rice bran, bakery wastes etc.) and/or commercial diets. In contrast, commercially produced aquafeeds are used in intensive pond culture operations. Credit schemes have made the shift to commercial feeds possible. Of particular importance are those schemes that are provided by local feed companies, as they provide credit to farmers that would otherwise have limited access to finance.

In contrast, some farmers have started organic farming operations in which the use of sex-reversed seed stock is avoided, and environmentally friendly practices, such as integrating tilapia farming with pig production or poultry farming is practiced. In these systems effluents/wastes from the terrestrial farming activities are utilized as a source of organic fertilization for the tilapia ponds.

Finally, the demand for tilapia in international markets has led to the development of farms that are designed to produce export sized tilapia (750–800 g). This production method normally requires stocking larger tilapia fingerlings (~50 g), which are produced through conventional means and the use of commercially formulated aquafeeds.

2. METHODOLOGY

An assessment of the current feed management practices in the Philippines was made. Primary data were obtained through personal interviews with selected farmers and technical staff in research agencies. The respondents were selected from hatchery and grow-out farms in Bulacan, Pampanga and Nueva Ecija (Region III) and in Rizal,

Laguna and Batangas (Region IV-A) (Table 3). The survey comprised seven tilapia cage hatchery operators, nine pond hatchery operators, five cage grow-out operators, and eleven pond grow-out operators. The farms were selected to provide a representative sample of small-scale (<2 tonnes per hectare per crop), medium-scale (2–5 tonnes per hectare per crop) and large-scale (>5 tonnes per hectare per crop) operations. Two questionnaires were prepared, *viz.* one for the hatchery operations and another for the grow-out operations.

TABLE 3
Details of the farms surveyed for the case study

Type/Location	Number of farms	Total farm area (ha) or number and size of cages
Cage hatcheries		
Region IV-A – Rizal	7	0.25–2 ha
Pond Hatcheries		
Region IV-A – Rizal	1	0.15 ha
Region IV-A – Laguna	1	5 ha
Region III – Nueva Ecija	5	1.65–10 ha
Region III – Pampanga	2	10–18 ha
Grow-out cages		
Region IV – Batangas	5 (intensive)	1–21 units of 10 x 10 x 20 m cages
Grow-out ponds		
Region III – Nueva Ecija	4 (semi-intensive)	0.6–40 ha
Region III – Pampanga	6 (1 semi-intensive and 5 intensive)	1.7–29 ha
Region III – Bulacan	1 (semi-intensive)	3 ha

Source: Field survey (2010).

3. RESULTS AND DISCUSSSION

3.1 Feeds and feed utilization

In aquaculture, feeds generally account for more than 50 percent of farm operational costs (Rana, Siriwardena and Hasan, 2009). Specifically, between 60–80 percent of the operational costs in intensive production systems are due to feeds, and in semi-intensive systems and between 30–60 percent of operational costs are attributed to feed and fertilizer costs (PHILMINAQ, 2007). In extensive and semi-intensive pond culture systems, fertilizers are applied to promote primary productivity. In tilapia cages set in eutrophic lakes, such as Laguna de Bay – the largest Philippine freshwater lake, feeding is minimal, and the tilapia rely on the natural productivity of the system for nutrients. In these systems, the unnecessary or excessive use of feeds, or the use of poor quality feeds, may negatively affect the environment (BFAR-PHILMINAQ, 2007).

3.2 Commercially produced complete feeds

Of the 426 registered commercial feed millers in the Philippines, 78 produce aquafeeds (Sumagaysay-Chavoso, 2007; PHILMINAQ, 2007). In recent years, there has been an increase in the number of local animal feed companies producing and distributing commercial tilapia feeds. Several of these companies produce phase diets (diets for the different growth stages) for tilapia. In contrast, a number of manufacturers (HocPo, Vitarich, B-meg and Santeh) produce 'generic' diets, meaning non-specific aquafeeds

(feeds meant for any fish species) – in this case either for milkfish or tilapia. Over time, feed manufacturers have diversified their products and increased production to supply the growing need for tilapia feeds. In 2006, the Bureau of Animal Industry (BAI) reported that the largest producers of aquaculture feeds in the Philippines were found in Region III (n = 32 feed companies), followed by Region IV (18) and the NCR (10) (PHILMINAQ, 2007).

The proximate composition of many of the commercially available tilapia feeds conform to the gross nutrient composition as outlined by Hasan (2007). Typically, the protein content is between 30 and 56 percent in fry feeds, 30–40 percent in the juvenile feeds, and 22–32 percent in the adult feeds. Lipid contents range between 5 and 12 percent, carbohydrates between 30 and 40 percent, and crude fibre between 4 and 20 percent. With respect to the feed costs, between 2005 and 2010 the average price of commercial tilapia fry feeds increased by 64 percent from US$0.47/kg to US$0.77/kg. During this period, fingerling and grow-out diets increased by 36 percent from an average of US$0.42/kg to US$0.57/kg (Hasan *et al.*, 2007 and this survey).

Farmers assessed the importance of various factors affecting their use and choice of feeds (Table 4). The farmers rated these factors between 1 and 10, with 10 being the most important. It was evident that farmers had little knowledge on how to assess feed quality, and simply relied on visual observations. In terms of water stability, the farmers do not test the feed at all. With respect to palatability, visual observation, and checking whether fish immediately ingested the diet after they had been administered, were the only criteria that farmers used. None of the surveyed farmers took note of the taste of the tilapia feed but deemed this criterion important, together with nutrient composition. Tilapia cage grow-out farmers rated feed quality at 9.8, suggesting that this factor was an extremely important consideration in their purchasing decisions. In contrast, tilapia cage hatchery operators rated feed quality at 7.5, indicating that feed quality was of less importance to them. This low score was due to the cage hatchery operators locating their spawning and larval rearing cages in a eutrophic lake with good primary productivity where, due to the natural productivity of the system, artificial diets are not so necessary.

TABLE 4

Evaluation scores of farmers on the importance of feed quality as a factor perceived to influence farm production and the associated costs

Criterion	Grow-out farms				Hatchery farms			
	Cages	Ponds			Cages	Ponds		
	Reg IV-A Batangas farms	Reg III Nueva Ecija farms	Reg III Bulacan farms	Reg III Pampanga farms	Reg IV-A Rizal f arms	Reg IV-A Rizal, Laguna farms	Reg III Nueva Ecija farms	Reg III Pampanga farms
Palatability	10.0	8.8	7.0	7.3	6.2	7.5	8.6	9.0
Water stability	10.0	9.3	7.0	8.6	7.6	9.0	8.8	8.5
Nutrient composition	9.4	9.3	10.0	7.5	8.7	9.5	9.8	8.0
Feed quality	9.8	9.2	8.0	7.8	7.5	8.7	9.1	8.8
Feed price	–	9.5	10.0	9.6	9.0	8.5	10.0	8.0
Regularity of supply	10.0	9.3	10.0	10.0	8.4	8.5	9.8	8.0
Brand used	10.0	10.0	10.0	8.4	8.4	9.0	8.0	8.5
Freshness	10.0	10.0	10.0	9.0	8.7	9.5	9.2	10.0
Reliability of feed labelling information	8.8	9.5	7.0	8.8	7.1	7.5	9.0	8.5

Source: Field survey (2010).

The perception of farmers with respect to feed costs, their availability and information on the ingredients and the quality used in commercial diet formulation was also recorded (Table 4); each was asked to assess the impact of these factors on their production costs. The respondent farmers considered price as an important factor in their farm operations. Supply or feed availability is as important but generally the farmers do not have any major problems with feed availability, since those who require feeds in bulk have their own feed storage facilities, or have the feeds readily delivered to them. On the other hand, those with minimal feed requirements are able to purchase them from small feed distributors or outlets. The feed brand is also important, although some farmers – especially those engaged in cage hatchery operations in Laguna Lake – administer any animal feed that is available at the time of purchase. For farmers that have access to technical information, feed brand and information on the ingredients used by the manufacturer are important factors that influence their decision on which commercial feeds to purchase. Feed freshness is also an important criterion as the farmers take note of sensory indicators – especially if they notice that the feeds are rancid and have an off-odour. The survey questionnaire originally included digestibility and the importance that farmers place on this as a criterion for feed quality and its influence on production costs. However, this criterion proved difficult for farmers to quantify, much less comprehend. It entails the measurement of a specific nutrient (e.g. protein) in the feed and faeces (Feed Development Section, 1994). Results of this part of the survey were not included because the respondents did not have a clear technical understanding of what digestibility meant.

In terms of evaluating the efficacy of commercial feeds, the farmers depend solely on the information that is presented on the feed packaging. As for the reliability of the information found therein, the only way for the farmer to validate the feed specification is to have a proximate analysis undertaken. However, the farmers do not have the means to do this. Generally, the farmers find the commercial feed manufacturers reputable, even though they do not have the nutrient composition of their feeds counterchecked; they believe that all the information on nutrient composition is credible – their scores on this factor were between seven and ten. Only when they find the fish to be growing poorly, when following the optimal feeding management schemes, will they doubt the veracity of the claims of the feed companies. In the Philippines, the BAI, the Bureau of Agriculture and Fisheries Products Standards (BAFPS) and the Fish Health Section of the Bureau of Fisheries and Aquatic Resources (FHS-BFAR) are the three agencies involved in feed regulation. Their roles are to ensure that the industrially-made aquafeeds meet the regulatory standards set. These agencies are mandated to perform the following specific functions (PHILMINAQ, 2007):

- BAI – regulates animal feeds, ingredients, veterinary drugs and products under the Livestock and Poultry Feeds Act (Republic Act 1556), which covers aquafeeds.
- BAFPS – under the Republic Act 8435 it sets and implements quality standards for preservation, packaging, labelling, importation, exportation, distribution and advertising of processed agricultural and fishery products standards for efficient trade; this agency has drafted standards for both commercial aquafeeds and Best Aquaculture Practices.
- FHS-BFAR – undertakes activities that ensure compliance to aquafeed quality and farm practices.

3.3 Farm-made feeds

Farm-made feeds are normally produced when the cost of commercial feeds is deemed prohibitive, and farmers believe that their use will be more cost effective. The advantage of producing farm-made feeds is that the farmers are assured of the freshness, quality and contents of the formulation. The key element in successfully producing farm-made feeds is the technical capacity of the producer. In the current survey, only one farm

used farm-made feeds. The owner of this farm operated a milling facility to produce pig and tilapia feeds, and used a consultant to advise on formulations. A major constraint to the production of farm-made feeds is access to necessary equipment and, regardless of the cost, many farmers find it more convenient to use readily available commercial feeds. In this regard, the survey revealed that only 6.25 percent of the farms regularly use farm-made feeds. In addition, one pond hatchery operator (GET farm) occasionally prepared farm-made feeds with duckweed (whenever this plant was available) (Figure 3). The ingredients that are available for inclusion in farm-made feeds are presented in Table 5. Typical formulations for practical tilapia diets are presented in Table 6.

FIGURE 3
A tilapia pond hatchery operator growing duckweed in his farm to utilize it in his farm-made feeds

COURTESY OF FAO/M.R.R. ROMANA-EGUIA.

TABLE 5
List of ingredients used in the production of farm-made feeds for a tilapia farm in Pampanga

Fry and pre-starter	Grower and finisher
Biscuit meal/wheat meal	Biscuit meal
Cassava meal	Cassava meal
Soybean meal	Soybean meal
Rice bran	Rice bran
Copra	Copra meal
Blood meal	Blood meal
Fishmeal	Fishmeal
Coconut oil	Coconut oil
DL-methionine	DL-methionine
Vitamin premix	Vitamin premix
Mineral remix	Mineral premix
Luctanox	Luctanox
Luctamold	Luctamold
Choline chloride	Choline chloride
Vitamin C	Vitamin C (coated)
Anti-salmonella	Yeast
T5X (toxin binder)	T5X (toxin binder)
Salt	Common salt
	Monodicalcium phosphate (MDCP)

Source: Jane Caras, Harvest Moon Farm, personal communication, 2010.

TABLE 6

Practical diet formulations (g/kg dry diet) for tilapia at various stages of culture

Ingredient	Broodstock diet 1	Larvae/fry diet	Grow-out diet
Fishmeal	362	301.7	182.5
Maize gluten meal	204	–	–
Soybean meal	177	259.5	250.0
Copra meal	118	114.8	100.0
Leucaena (ipil ipil) meal	–	81.0	–
Cassava flour	–	–	364.2
Rice bran	75	149.7	60.0
Starch	32	30	–
Cod liver oil	5	10	–
Vegetable oil	5	10	–
Vitamin & mineral premix	22	43.3	43.3
Proximate composition (% dry matter)			
Crude protein	44.0	38.1	28.1
Crude fat	5.5	8.7	3.8
Crude fibre	9.1	5.6	3.6
Nitrogen free extract	29.6	30.8	54.6
Ash	11.8	16.8	9.9

Source: Santiago, Aldaba and Reyes (1987); Santiago *et al*. (1985; 1986).

The feedstuffs presented in Table 6, and the other components of the farm-made feeds (Table 5, Sumagaysay-Chavoso, 2007) are sourced locally. With the exception of fishmeal, which is either locally available or imported, most of the ingredients used in the farm-made feeds are affordable, and thus farm-made feed formulations remain economical feed options.

The major ingredients used in tilapia aquafeeds, both commercial and farm-made, are maize and maize by-products, soybean, copra meal and fishmeal (e.g. Table 6). Farm-made aquafeeds may incorporate aquatic and land-based plant materials (duckweeds, *Azolla*, water hyacinth), animal materials (snails, clams, silkworm larvae, maggots), plant processing by-products (de-oiled cakes and meals, beans, grains and brans) and animal processing by-products (blood and feather meal, bone meal) (Rana, Siriwardena and Hasan, 2009). Table 7 provides information on the cost of selected feed ingredients.

TABLE 7

2010 prices of commonly used feed ingredients for tilapia diets

Ingredient	Cost (US$/kg)
Maize and maize by-products	
Yellow maize – grains	0.31
Yellow maize – grits	0.31
Copra	
Copra cake	0.18
Copra meal	0.19
Soybean meal	
Soybean meal (United States of America)	0.53
Soybean meal 46% (Argentine Hi-pro)	0.50
Fishmeal	
Fishmeal 60% (United States of America)	1.06
Fishmeal 60% (Thailand)	1.23

US$1.00 = PhP 46.00 as of July 2010.

Source: Philippine Superfeeds Corporation, Navotas, Metro Manila, Philippines, 2010.

Of the ingredients listed, imported fishmeal is the most expensive, and at US$1.23/kg it is more than twice as costly as imported soybean meal (US$ 0.53/kg). In addition to the expense, fishmeal has become difficult to source, and this has affected both the availability of commercial aquafeeds and the production of farm-made aquafeeds. The high cost and availability problem associated with fishmeal use has led researchers to focus on the identification of alternative protein sources. Fishmeal replacement studies have been undertaken on soybean meal, soy protein concentrate, pea protein concentrate, cottonseed cake, maize gluten, poultry by-product meal, and feather meal (Li, Lim and Webster, 2006).

3.4 Supplemental feeds

Supplemental feeds are often used when farmers increase the stocking density and standing crop of the production system and the natural foods become insufficient to support optimal growth. Supplemental feeds used include rice bran, maize meal, copra meal, coffee pulp, brewery wastes or by-products, and chicken feed, bread crumbs (Alava, 2002). Although these are normally high-energy feed sources, they are low in terms of protein levels and micronutrients (Feed Development Section, 1994). Though nutritionally incomplete when administered singly, the use of supplemental feeds are more economical as they are cheap nutrient sources. Of the surveyed farmers, two out of the seven practicing lake-based hatchery farming supplement their breeders and sometimes their seed stock with bread crumbs or rice bran. Many of the lake-based hatchery operators, particularly in the Rizal province, are subsistence fish farmers and are unable to afford commercial aquafeeds; instead they use cheaper supplemental feeds. Production expenses are primarily confined to the purchase of broodstock, cage/module fabrication and maintenance, and transportation. If they can afford commercial aquafeeds, they are usually used as broodstock feeds, with feeding normally being restricted to alternate days. Only one of the seven surveyed lake-based hatcheries used commercial aquafeeds on a continuous basis to feed their breeders and seed stock.

3.5 Feed additives

The main additives used in tilapia feeds are vitamin C and α-methyl testosterone. Both are used in hatchery feeds. Two out of the 16 hatcheries surveyed use vitamin C in their broodstock diets to improve egg quality and enhance disease resistance. Three of the 16 hatcheries surveyed produced sex-reversed all-male tilapia seed stock by feeding newly hatched fry with diets containing α-methyl testosterone. Sixty percent of the surveyed commercial tilapia pond hatcheries in Nueva Ecija follow a standard protocol for sex-reversal through hormonal manipulation. These incorporate doses of 50–60 mg α-methyl testosterone per kilogram of feed. The feed is administered to the tilapia fry for 21 to 23 days to obtain a population of 90–95 percent males. One farm reported using the hormone treatment for 35 days. Alpha-methyl testosterone is imported from Germany and costs US$ 36.5 per 10 g. With the added cost for the hormone, sex-reversed seed stock are 20 percent more expensive than normal tilapia seed stock.

3.6 Fertilizers

Fertilizers are used in extensive and semi-intensive pond culture systems. The survey revealed that inorganic fertilizers, including mono-ammonium phosphate (16-20-0 or 16 percent N, 20 per cent phosphate), urea (46-0-0), ammonium sulphate (21-0-0), and 14-14-14 are used. The most commonly applied organic fertilizer was chicken manure. It has been reported that in 2000–2001, 50 percent of the inorganic fertilizers used in the aquaculture industry were imported (ADB, 2005b). A summary of the fertilizer application practices amongst the surveyed farmers is presented in Table 8.

TABLE 8
Mode of pond fertilization in the tilapia farms surveyed in different provinces

Parameters	Nueva Ecija	Pampanga	Bulacan
Type	**Inorganic**	**Inorganic and organic**	**Inorganic and organic**
Grow-out ponds			
Fertilizers	Urea (46-0-0) and Ammonium phosphate (16-20-0)	Farms use two, three or all of the following: Urea (46-0-0) Ammonium phosphate (16-20-0) Ammonium sulphate (21-0-0) Nitrogen-phosphorus-potassium (14-14-14) Chicken manure	Ammonium phosphate (16-20-0) and chicken manure
Fertilization rate/amount used	20 kg 46-0-0, 5–6 kg 16-20-0 (mixed/hectare/week)	20–80 kg 46-0-0/ha 20–200 kg 16-20-0/ha 30–80 kg 21-0-0/ha 20–40 kg 14-14-14/ha 30–50 bags chicken manure/ha	100 kg 16-20-0/ha 50 bags chicken manure/ha
Cost	16-20-0: US$17.6/50 kg Urea: US$17.8/50 kg	16-20-0: US$15.6/50kg to US$20/50 kg 46-0-0: US$19.6/50kg to US$21.3/50 kg 21-0-0: US$11.7 to IS$11.9/50 kg 14-14-14: US$18.7 to 19.6/50 kg Chicken manure: US$1.3/50 kg	16-20-0: US$17.8/50 kg Chicken manure: US$1.1/50 kg
Method of fertilization	Fertilizer dissolved in bucket and then dispersed on the pond surface; this is done 6 times during the entire culture period	Broadcasting (dispersed from one side of the pond) or hanging method	Broadcasting
Hatchery ponds			
	Laguna and Rizal	**Nueva Ecija**	**Pampanga**
Fertilizers	Farmers use either 16-20-0 and chicken manure or chicken manure alone	Farmers use either 46-0-0 and 16-20-0 or 16-20-0 and chicken manure	Farmers use any two or all of the following: 46-0-0 16-20-0 chicken manure
Fertilization rate/amount used	1 kg 16-20-0/pond 50–100 kg chicken manure/pond	50–100 kg 46-0-0/ha 30–100 kg 16-20-0/ha 50–200 kg chicken manure/ha	100 kg 16-20-0/ha 100 kg 46-0-0/ha 100 kg chicken manure/ha
Cost	16-20-0: US$17.6/50kg Chicken manure: US$0.54 to 0.87/50kg	16-20-0: US$17.4–26.1/50 kg 46-0-0: US$17.4–26.1/50 kg Chicken manure: US$0.98/50 kg	16-20-0: US$18.5–21.7/5 0 kg 46-0-0: US$18.5–21.7/50 kg
Method of fertilization	Broadcasting	Broadcasting	Broadcasting

Note: US$1.00 = PhP 46.00 as of July 2010.
Source: Field survey (2010).

Pond fertilization practices vary between farmers and the use of inorganic and organic fertilizers varies with the intensity of the culture operations (e.g. intensive tilapia pond farming, pond-based seed stock production). Fertilizers are usually spread by broadcasting, not the tea-bag or hanging method. The traditional tea-bag or hanging method allows the fertilizers to gradually leach out; this occurs in the area of the pond where they are hung, and hence fertilization is slow and inefficient. The tea bag method was practiced at a time when fertilizers were relatively inexpensive. The broadcast method allows the fertilizer to be spread or dispersed much faster and more evenly throughout the pond; hence, in the long term, it proves to be more economical. A summary of fertilizer costs in 2009 is presented in Table 9.

TABLE 9

Whole-sale prices of fertilizers available in the major tilapia producing regions in the Philippines (2009)

Fertilizer	Region	Price (US$/kg)
Ammonium phosphate (16-20-0)	Region III (Central Luzon)	22.38
	Region IV-A (Calabarzon)	26.45
Ammonium sulphate (21-0-0)	Region III (Central Luzon)	12.74
	Region IV-A (Calabarzon)	15.98
Urea	Region III (Central Luzon)	19.69
	Region IV-A (Calabarzon)	22.82
Chicken manure*	Region III (Central Luzon)	0.97
	Region IV-A (Calabarzon)	1.09

Source: BAS (2010); *Field survey (2010).

US$1.00 = PhP 46.00 as of July 2010.

The retail prices for fertilizers varied between regions and, in contrast to Region III, are slightly higher in Region IV-A. The probable reason for the price difference is that these fertilizers are also used for agriculture in Region III, where crops such as rice are farmed – a region known as one of the major rice-producing areas in the Philippines. Region III (Central Luzon) therefore has more fertilizer brands and supplies in the market compared to Region IV-A, their costs in Region III less prohibitive. Organic fertilizers, such as chicken manure, are the cheapest fertilizers available. The cost of inorganic fertilizers is generally higher, with the most expensive being ammonium phosphate (16-20-0).

3.7 Current feed management schemes

3.7.1 Feed selection

The selection of feed by farmers is usually based on affordability and quality. Quality is primarily measured as a function of the growth performance and survival achieved; several respondents indicated that their choice was based on past feed performance using a particular feed. From a more technical perspective, one of the more important criteria for feed selection is their efficiency in terms of their feed conversion ratios (FCR). Unfortunately, with the exception of farms that are managed by academic research and government agencies, farmer-operators of private hatchery/grow-out facilities are not familiar with using FCR as a measure of feed efficiency. Many farms, particularly grow-out operations, have limited financial resources and have to procure feeds on credit. Under this scenario, the feed supplier is paid for the feed inputs once the tilapia have been harvested and sold. Using this financing paradigm, several pond-based grow-out farms, specifically those in the major tilapia producing province/region of Pampanga, use feed from companies that offer loan/financing schemes; they are more concerned with maintaining access to the feed, than its cost. An exception was one pond-based hatchery (GIFT Foundation International Inc or GFII), which utilizes the same brand for broodfish and seed stock because its manufacturer, Feedmix Specialists Inc., is supporting GIFT Foundation research and development activities. According to their operations manager, GFII is able to recoup its high cost of production on the price of the seed stock, which they sell at premium prices. This selection by GFII also supports its claim to having the experience of being able to produce better quality seed stock. When GIFT tilapia fingerlings are sold, the use of Feedmix feeds by the grow-out farmers is optional.

Another factor that influences the choice of feed/feed brand that farmers use is the aggressive marketing and promotional schemes of the manufacturers. Some feed companies form 'business clubs' for their loyal clients and encourage new clients to try their feed products. The 'incentive' for joining clubs would mainly be easier access to a credit scheme and to technical assistance. Locally-based feed companies employ research personnel/consultants to conduct aquafeed research, and undertake on-farm production trials to develop new feeding regimes that are then recommended to the farmers. However, under intensive marketing pressures, there is concern that the farmers are easily convinced to use excessive amounts of feed, and fail to follow optimal feed management strategies. In this regard, many of the farmers in the survey, notably the grow-out farmers, tend not to adopt optimal feed management practices, and in many cases overfeed their fish. Feed distributors also aggressively promote their products and have sales agents that visit farms to promote them. If purchases are made in bulk, the feeds will be delivered to the farm site. Moreover, as mentioned earlier, many of these feed companies have their manufacturing plants close to the tilapia production centres. Feeds are either delivered directly from the feed manufactures, or are readily available from small feed suppliers that are located close to the farms.

The majority of the farmers use a single brand, except when they intend to follow a scheme that would help to reduce feed costs. Some hatchery operators use high-cost commercial feeds and administer them alternately with low-cost commercial diets. High-cost commercial feeds, which normally have higher crude protein levels than low cost feeds, are fed to broodstock especially during the conditioning phase, with the assumption that the breeders will have better spawning performance and enhanced reproductive efficiency. Several farmers utilize a single brand and administer fry, fingerling, broodstock formulations, which have been introduced by the feed sales agent. Feed companies have now developed phase diets and now sell various feed types depending on the growth stage of the tilapia. The phase diets are formulated according to the nutrient requirements of each growth stage of the fish (Table 6).

Farmers who prefer to store feeds on their farms normally have storage facilities. Feeds are not kept long enough to allow them to spoil. A typical storeroom for feeds at a tilapia hatchery is presented in Figure 4. The results of the survey revealed that while all the grow-out farms have feed storage facilities, only 50 percent of the hatcheries store feeds on the farm. The survey revealed that only two out of 24 farms had optimal storage conditions. The storage facilities differed in size, with the smallest stock room holding 30 bags (25 kg feed/bag), and the largest having capacity for 2 000 to 7 000 bags per month. The surveyed hatcheries without feed storage facilities are mostly those that produce seed stock in lake-based cages. Under sub-optimal storage conditions, feeds spoil easily and become contaminated with moulds, mycotoxins (from fungi) and bacteria (Rana, Siriwardena and Hasan, 2009). In this regard, to prevent feed spoilage, the farmers need to be well informed on how to store feeds appropriately. Moreover, if feeds must be stored in bulk to save on feed, procurement and transportation costs, farmers need to ensure that the feed is rotated such that shelf lives are not exceeded, and the feed is used on a first-in: first-out basis. In this regard, the majority of the farmers in the survey were adopting appropriate storage periods, based on the capacity and condition of their storage facilities. Some respondents indicated that on occasion, feed spoilage was an issue in terms of the feed becoming wet and infested with insects. The respondents indicated that spoiled feeds are unfit for use, as they lead to an increase in the incidence of disease and mortality.

The following factors affect nutrient stability in feeds during storage: a) the moisture content of the feed; b) the relative humidity; c) elevated temperatures; d) air circulation; e) lipid peroxidation, which may cause feed rancidity; f) insect infestation; g) fungal proliferation; and h) bacterial contamination (Golez, 2002; Rana, Siriwardena and Hasan, 2009). Such factors can be avoided if the storage facility is clean, dry, well

FIGURE 4
Farm storage facility for aquaculture feeds at the GIFT Foundation International Inc., Nueva Ecija

COURTESY OF FAO/M.R.R. ROMANA-EGUIA.

ventilated, secure, and not directly exposed to sunlight. In addition, feeds should be properly labelled and stacked on a slightly elevated platform to allow air to circulate (Feed Development Section, 1994; Golez, 2002). Most of the farmers in the Philippines are not familiar with feed storage issues, and as a result tend to learn about them only when they experience specific problems.

The bulk storage of feeds saves transportation costs. Those farmers that do not have storage facilities, or for financial reasons are unable to buy feeds in bulk, are able to purchase feeds from the local feed dealers as and when they are required (either on a per kilo basis or in 25 kg bags); they then transport them from the dealership to the farm themselves. Alternately, for bulk purchases, the feed dealer may deliver, and charge transport costs. Some feed companies set quotas (e.g. 200 bags minimum) for purchases made in bulk, and this entitles the farmer to free feed delivery.

3.7.2 Feed management

Feeding management practices are species-, site- and input-specific. All the tilapia grow-out farms that were surveyed practiced monoculture. The only farms that practice freshwater polyculture using tilapia are the pen culture systems in Region IV-A, particularly those in Laguna de Bay where the primary culture species are either milkfish or bighead carp. In 2008, these culture systems contributed only 11 997 tonnes out of a total 257 133 tonnes, or 4.7 percent of the total tilapia production in the Philippines (Table 2; BFAR, 2008). In terms of national tilapia production, this level of production is minimal, and thus this sub-sector was not covered in the present survey.

Philippine tilapia production is primarily undertaken in intensive pond culture systems in Pampanga. The majority of the grow-out farms surveyed there prepare their ponds for stocking, using both inorganic and organic fertilizers (Table 8), followed by the feeding of commercially produced aquafeeds. Once natural productivity is established in the ponds, some of the farmers delay or restrict the use of aquafeeds for up to a month to take advantage of natural feeds; feeding is initiated if the farmers notice that the primary productivity has declined. Alternatively, Pampanga farmers (ponds size: 3 to 9 hectares) feed their stocks commercial diets twice daily. Initial feed rations

are 15 percent of the total fish biomass per day for three months, gradually reducing to two percent as the fish grow; feed is given thrice daily in the final month prior to harvest. A final average harvest size of 250 g is obtained. Conversely, tilapia produced in Nueva Ecija are grown in semi-intensive pond culture systems where artificial feeds (or sometimes supplemental feeds) are used in occasionally fertilized ponds. Both intensive pond culture farms in Pampanga and semi-intensive pond culture systems in Nueva Ecija have access to the genetically improved and sex-reversed tilapia seed stock produced in those regions.

In Region IV-A, the majority of the tilapia production is derived from Batangas' Taal Lake, and is based on intensive cage culture systems that use commercially produced aquafeeds (Figure 5). Cages here typically measure 10 x 10 x 20 m^3 and are stocked at a rate of 100 000 to 300 000 mixed-sex tilapia fry per cage. With this high stocking density and lake primary productivity that is insufficient to provide sufficient natural food, the farmers have to use compound aquafeeds. Feeding is undertaken throughout the three to eight month culture period, at three to five percent of the total fish biomass per cage. Feed rations are dependent on the stocking density and prevailing weather conditions; this entails reducing rations when weather is cooler than usual. Dietary formulations (fry, fingerling and grower) are administered as stocks are reared from fry to marketable size. Marketable fish could either be of assorted sizes, or of four to five pieces to a kilogram (200 – 250g each) after five months. This means that some of the farmers do not sort the fish or do selective harvesting, as they are not particular about the size composition of the harvested tilapias.

FIGURE 5
Use of commercially produced aquafeeds in intensive cage farms in Taal Lake

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The primary difference between intensive tilapia cage farming and pond farming is the percentage survival. The survey revealed that intensively farmed tilapias in ponds survive at higher rates (60 to 80 percent) compared to intensively farmed caged tilapias (50 percent). Cage grow-out operators particularly in Batangas do not own the farms themselves but are salaried farm technicians, who may not have an adequate technical background but learn the trade through experience. They do not mind if the harvested tilapia is half of the total stocked population as long as the yield is sufficient to allow the farm owners to earn a profit. The yields from cages are low because the farmer-operators intentionally overstock the cages. Their premise is that, even if half of the stock dies, they are still assured a harvest that will enable the owners to a earn profit; and at the same time provide the technicians with their salaries.

Finally, in intensive culture systems, and in particular in pond culture systems, farmers are increasingly using greenwater systems. Thus, in addition to managing feed, water and dissolved oxygen levels, primary productivity is also managed (which requires fertilizer inputs). The management of primary productivity results in improved growth and survival rates.

Although feed prices are high, the majority of farmers do not formulate or make farm-made feeds. Farm- made feeds are not difficult to prepare, and the production

techniques can be easily learnt using low cost equipment that is readily available (Figure 6). These skills are taught in agencies such as SEAFDEC/AQD as well as in some stations of the local fisheries bureau. Despite the availability of these courses, many farmers elect to use the commercially available aquafeeds that are readily available in the market.

FIGURE 6
Basic equipment used for making farm feeds at SEAFDEC/AQD Binangonan Freshwater Station: feed mixer (left), meat grinder/pelletizer (middle) and fabricated feed dryer (right)

COURTESY OF FAO/M.R.R. ROMANA-EGUIA.

Farmers adopt feed management practices that optimize feed use and reduce operational costs. In this regard, local researchers have undertaken studies to determine whether feed management practices designed to reduce feed costs adversely affect tilapia growth. Bolivar, Jimenez and Brown (2006) demonstrated that feeding tilapia on alternate days did not significantly impact growth and survival. Additional feed management practices, including alternate feeding and delayed early feeding, have been tried; these show promising results. Some farmers have adopted these management practices and, as a consequence, have reduced their production costs. In addition, other researchers have undertaken exploratory work to determine the effect of variable feeding schedules and diets on the growth and fry production of Nile tilapia (Santiago and Laron, 2002). This research involved the use of high and low protein diets for both fingerlings and broodfish. The results demonstrated that the feeding schedules significantly influenced female body weight. Broodfish fed alternately with high-protein and low-protein diets produced the highest growth, fry production and feed cost savings.

3.7.3 Feeding strategies

In order to optimize growth rates and FCR, feeding strategies take into consideration ration size, feeding frequency and duration, appetite, feeding method, and feed monitoring. Feeding strategies need to take into consideration the nutritional requirements of the fish under different culture environments. Specific feeding strategies have been developed for tilapia broodstock, larvae and grow-out. Broadcasting feeding techniques are used, and the feed response is visually monitored so that feeding is ceased once the fish reach satiation.

3.8 Tilapia broodstock and hatchery operations

3.8.1 Cage-based hatcheries

Simple feeding methods are applied to cage-based hatchery facilities. These culture systems are common in Laguna Lake, Philippines (Figure 7), where the high natural productivity of the system supplies much of the nutritional requirements of the fish.

The need to supply additional nutrition through the application of compound aquafeeds is perceived as minimal, and therefore less than that administered in tank or pond based systems. Some of the tilapia hatchery operators in the lake employ techniques that are technically unsound or have no clear scientific basis. For instance, some of them have little knowledge about the adverse effects of: a) using broodstock from the wild which are of unknown ages and ancestry; b) pairing closely-related breeders; c) developing poorly selected potential broodstock from slow-growing unsold hatchery-bred fingerlings; and d) utilizing undernourished broodstock that are totally reliant on natural food in contrast to those fed with complete diets that enhance the their reproductive performance. Due to limited resources, broodstock are obtained from the wild, and are spawned at sex ratios of 1:5 or 1:10 (male:female). Sex ratios of 1:10 are high and considered sub-optimal. The usual sex ratios that are confirmed as effective and are adopted in tilapia pond hatcheries are between 1:1 to 1:4 or 1:5 (Bautista, 1988). Sex ratios beyond 1:5 (male:female) cause undue stress or spawning fatigue to the male stocks. Moreover, due to a poor understanding of the nutrient requirements of the broodstock that are spawned in cages, farmers do not always use supplemental broodstock feeds; this can result in suboptimal reproductive performance. In the absence of broodstock diets, lower seed yields can be expected. Instead of broodstock diets, some farmers use diets meant for other aquatic species, or even for poultry. These feeds are cheaper and do not contain the nutrients required for tilapia broodstock.

FIGURE 7
Hapa-based tilapia cage hatchery in Laguna Lake

COURTESY OF FAO/M.R.R. ROMANA-EGUIA.

3.8.2 Pond-based hatcheries

In comparison to cage-based hatcheries, the operation of pond or hapa-in-pond hatcheries (Figure 8) are both labour and input intensive. Pond hatcheries require more technically proficient operators than cage based hatcheries. With respect to yield, semi-intensive pond hatchery systems require more feed/fertilizer inputs than semi-intensive cage hatcheries. However, pond hatchery operations are more profitable (Table 10). The technology for tilapia seed stock production in ponds is more developed and cost-efficient than that applied to the cage systems. Feed management starts with the breeders used to produce the tilapia seed stock. Feeding is more frequent and the ration is defined at 1–2 percent of fish biomass. Except for one lake-based hatchery owner-operator, who has access to updated technical information from a nearby aquaculture research institution, most of the small-scale cage hatchery operators do not normally feed their broodstock artificial diets. Supplemental feeding is only undertaken if the farmer has extra funds to purchase feeds. The same is true for the feed management practices that are applied during the hatchery and nursery production phases. In comparison with pond culture operations, cage-reared tilapia fry are fed less frequently, as the farmers rely on the natural feeds in the water body. Conversely, the feeding strategies that are adopted in ponds (e.g. frequent feeding with formulated feeds) are well defined, and particularly so for the early larval stages. Early larval feed management strategies promote the production of strong fry/fingerlings with improved survivorship characteristics; even when commercial feeds are costly, the pond hatchery

operators invest in them as they are assured better yields. A summary of the current hatchery rearing practices and accompanying feeding strategies is presented in Table 10, which includes an analysis of the gross returns (income from sale proceeds of fingerlings minus feed and fertilizer costs) from nursery feeding management.

FIGURE 8
Hapa-in-pond tilapia hatcheries in the Philippines

COURTESY OF A. LAZARTIGUE, SEAFDEC/AQD

TABLE 10
Management systems in small and large-scale tilapia hatcheries

Parameters	Cage hatcheries*	Pond hatcheries*
Broodstock management		
Size of broodstock enclosures	a) 5 x 12 x 1.5 m^3 b) 8 x 25 x 1.5 m^3	a) 100–1 000 m^2 b) 3 200 m^2
Total number of broodstock	a) 60 males and 600 females b) 2 000 males and 9 000 females	a) 6 000 b) 8 000–15 000
Type of incubators, if any	None	a) Recirculating system, jar type b) Downwelling incubators
Strain used	a) Wild (from Laguna lake) b) IDRC or FAST	a) GIFT G11 (GIFT Generation 11 2003) b) Genomar
Sex ratio for spawning	a) 1 Male: 10 Females b) 1 Male:5 Females	1 Male:3 Females
Initial broodstock size – final broodstock size	a) 100–300 g; b) 350–1 000 g (after 6 months to 1 year)	100–150 g females; 100–200 g males
Duration of use	a) 6 months b) 1 year	a) 2–3 years b) 1 year
Broodstock management	a) only males are replaced after 6 months b) both sexes totally replaced after 1 year	Total replacement
Average no. of eggs or fry/female	200–250	200–1 200
Broodstock feeding strategy		
Feeding frequency	a) Feeds given only as needed and when available b) once per day, alternate days	Twice per day
Time of feeding	a) No specific time b) 0900 hours	a) 0830 to 0900 hours, 1400 to 1500 hours b) 1000 hours, 1600 hours
Amount of feed	a) 1 kg ration for fish in 6 cages b) 2.5% of BW	a) 2% of BW; stocks sampled b) 1–2%, adjusted every 2 months
Feed brand/type used	a) Dry, sinking b) B-meg grower – dry, sinking pellets (28%CP); broodstock feed important, especially as it enhances the reproductive performance of the fish	a) Feedmix floating pellet b) Purina (high value)/Hoc Po (low value)
Feeding method	Manual, broadcasting	Manual, broadcasting
Feed monitoring	Regular	a) Regular b) Every two months
Growth performance of broodstock	Just right, controlled	a) Moderate from 200 g initial to 400 g final b) Moderate
Strategy to save on feed cost	a) Supplemental feeding practiced; very minimal feed inputs b) Skip feeding to supplement natural food already present in the lake	a) Skip feeding; reduction of amount from 3% to 2% daily b) Alternate feeding of fish with high-value then low-value feeds; high-value feeds given especially prior to conditioning

Parameters	Cage hatcheries*	Pond hatcheries*
Hatchery (fry) feeding management		
Feeding frequency	a) 3 times/week b) 6 times/day (to fry size 24)	a) 6 times/day b) 8–10 times/day with Tateh-brand commercial feeds for weeks 1–2 then 5–6 times/day for weeks 3 and 4
Time of feeding	a) No fixed time; mornings only b) 3 times in the morning and 3 times in the afternoon	a) 0800, 0900, 1000 hours/1400, 1500, 1600 hours b) Every hour
Amount of feed	a) 1 kg feed ration for 2 cages containing 70–80 tilapia/cage b) 5% of BW; adjusted weekly through regular sampling	a) Week 1 = 30%, 2 = 20%, 3 = 10% b) 100%; note that ponds lack natural food, as they are lined
Brand/type of feed	a) Any dry sinking b) B-meg fry mash/dry sinking	a) Feedmix floating SP1 and SP2 b) Tateh Fry booster
Feeding method	Manual	Manual
Average fry survival	a) 50% from fry to size 24 b) 90% from fry to size 24 (2 weeks under favourable conditions; 4 weeks if otherwise)	a) 70–85% (especially after MT treatment) b) 65–85%
Type of fry produced	Normal	a) Sex-reversed b) Sex-reversed
Reversal method	N/A	a) 50–60 mg alpha-methyltestosterone (MT)/kg used; 21–23 days treatment b) 50–60 mg MT/kg used; 21–23 days treatment
Nursery feeding management		
Feeding frequency	a) 3 times/week b) 3 times/day from size 24 to size 14	a) 3 times b) no nursery phase; seed stock sold easily
Time of feeding	a) Morning only b) 3 times/day	a) 0900 hours, 1100 hours, 1500 hours
Amount of feed	a) Ration divided among caged stocks b) 5% of BW	a) 5%
Feed brand and type	a) None in particular b) B-MEG fry mash, sinking dry	a) Feedmix, floating
Days of culture of seed stock	a) 14 days from fry to size 17/14 b) 30 to 45 days from size 24 to size 14	30 days from size 20–17
Production per run	a) 80 000 b) 1 million	a) 1 million/month b) 2 million/month
Estimated gross returns based on the feeds/fertilizers used	a) Very minimal feed inputs; US$870 value of 80 000 fingerlings; Return = US$870 b) US$4 891 cost of feed inputs; US$9 783 value of 1 million size 14 fingerlings; Return = US$4 892	a) US$1 574/month for feed inputs, US$522/month for fertilizer inputs; US$14 130 value of 1million/month of size 14 fingerlings; Return = US$12 034/month b) US$17 374/month for feed inputs, US$26 957 value of 2 million/month of size 14 fingerlings; return = US$9 583
Feed additives used	None	None vitamin C for broodstock
Seed stock transport	a) boat hull b) plastic bags, aerated boxes	plastic bags

**Source and key:* a) = low to medium input farms (cage hatchery data based on information provided by D. Santiago and pond hatchery data obtained from GIFT Hatchery); b) = high input farms (cage hatchery data based on information provided by East Cove Hatchery and pond hatchery data obtained from PhilNor Aqua Inc.); inputs refer to number of broodstock used and feed and better management inputs.

3.9 Tilapia grow-out operations

Tilapia grow-out farms in the Philippines are either based on semi-intensive or intensive pond culture technologies. These culture practices are widespread in the province of Pampanga and Nueva Ecija. This area is ideal as it is close to the seed stock sources based at Munoz, Nueva Ecija. In addition to the pond grow-out systems, cage culture systems are used in Batangas. The strategies for on-growing tilapia in ponds are well established and researched (Eguia and Romana-Eguia, 2007). Approximately 45 percent of the surveyed pond grow-out operators have benefited from technical support. In comparison, none of the cage grow-out farmers that were surveyed had

received any formal technical training or support, and it is assumed that their technical knowledge was provided by the feed distribution companies. Table 11 provides an outline of the methods that are used for grow-out production, and includes an analysis of the gross returns (income minus feed and fertilizer costs) from grow-out feeding management. The feed consumption, yields and feed conversion ratios attained in the different culture systems is presented in Table 12.

TABLE 11

Management systems in small and large-scale tilapia grow-out farming systems

Parameters	Cages	Ponds
Size of culture enclosures	10 x 10 x 20 m^3	a) 20 000–60 000 m^2 b) 10 000–30 000 m^2
Total no of seed stock per cage	a) 100 000/cage (50/m^3) b) 260 000/cage (163/m^3)	a) 2/m^2 at 50g/piece a) 4/m^2 at size 14* (1.5 cm)
Strain used	Mixed-sex hatchery seed stocks from Laguna/Laurel, Batangas	a) GIFT-derived strain b) Hatchery bred, parental stock from SEAFDEC
Initial stocking size	Sizes 22 to 17* (1.00–1.25 cm)	a) Advanced fingerlings (50 g) b) size 14* (1.5 cm)
Culture method	Intensive	a) semi-intensive b) intensive (full feeding)
Days of culture	a) 8 months b) 3 months	a) 7–8 months (target size = 700–800 g) b) 3.0–3.5 months
Feeding frequency	a) 3–4 times/day for 2 months and 2 times/day from month 3 to month 8 b) 2 times/day	a) 2–3 times; 3 times for smaller fish b) 2 times/day for 2 months and 2–3 times for remaining month
Time of feeding	a) 08.00 hours, 12.00 hours and 16.00 hours; then 09.00 hours and 15.00 hours b) 09.00 hours and 15.00 hours	a) 09.00 hours and 15.00 hours b) 09.00 hours and 15.00 hours; then 09.00 hours, 12.00 hours and 16.00 hours
Amount of feed	a) 5 kg/day for months 1–2; 120 kg/day for months 3–8 b) 6 bags/day (150 kg/day) during good weather; 5 kg during bad weather	a) 2–3% BW; 400 bags/cropping b) size 14 (2 g); 15% BW; 3–5 g; 10%; 6–22 g: 7%; 22–39 g: 6%; 40–65 g: 5%; 66–75 g: 4%; 91–120 g: 3%; 121–200 g: 3%; 201–251g: 2%
Feed brand/type used	a) Feedmix SP1to GT35 (floating then sinking) b) B Meg floating pellets	a) Global-brand aquafeed b) Farm-made feed
Feeding method	Manual, broadcasting	Manual, broadcasting
Feed monitoring	Regular	Regular
Feed conversion ratio	No idea	a) 1.5:1–1.7:1 b) ~1:1
Growth performance	Good	a) Good, 50 g fish reach 700 g + in 7–8 months b) growth is faster when fed
Percentage yield or survival	a) 50% (Mar–Apr); 30% (Oct–Feb) b) Total yield = 20 tonnes	a) 60% b) 88%
Strategy to save on feed cost	Skip feeding if selling price of fish is low	a) none
Benefit-cost ratio estimate based mainly on feeds/ fertilizers used	a) 600 bags/cropping/cage used, hence US$9 130 cost of feed inputs; US$15 217 to US$19 022 value of harvestable tilapia at US$1.52/kg; Return = US$6 087 to US$9 891 (note: 50% survival) b) 250 bags/cropping/cage used, hence US$3 804 used for feed inputs; US$9 130value of harvestable tilapia; Return = US$5 326	a) 400 bags/cropping used, hence US$6 217 used for feed inputs; US$12 043 value of marketable sized tilapia (700 g each); Return: US$5 826 b) no data were given on feed cost for farm made feeds; according to the farm operator, they were able to break-even

Note: a) low to medium input farms (data from Pops Cage farm and SAAFI Inc.); b) high input farms (data from T. Dizago Cage farm and Harvest Moon Tilapia pond farm); inputs mean stocking density, feed and/or fertilizer inputs.
*tilapia fingerling size – the figure in brackets refers to the mesh size of the net used in sorting fish.

Source: Field survey (2010).

TABLE 12
Feed conversion ratios based on feed consumption and yield data of the surveyed farms

Location	Feed consumed (kg)	Fish yield (kg)	FCR
Cage-based, Region IV-A			
Pops Enterprises Agoncillo, Batangas (intensive)	16 500	15 000	1.1:1
G Desagun Farm Agoncillo, Batangas (intensive)	11 250	7 000	1.6:1
S Encarnacion Farm Agoncillo, Batangas (intensive)	~11 250	30 000	<1:1
T Dizago Farm Agoncillo, Batangas (intensive)	~6 000	26 000	<1:1
V Villanueva Farm Agoncillo, Batangas (intensive)	~15 000	24 937	<1:1
Pond-based, Region III			
FAC-CLSU Munoz, Nueva Ecija (semi-intensive)	–	–	1.2:1–1.5:1
PhilNor Aqua Inc San Miguel, Nueva Ecija (semi-intensive)	–	–	1.2:1
R Limos Farm Sto Domingo, Nueva Ecija (semi-intensive)	2 500	2 500	1:1
San Antonio Aqua Fisheries Inc. (SAAFI) San Antonio, Nueva Ecija (semi-intensive)	–	–	1.5:1–1.7:1
E Lulu Farm San Luis, Pampanga (intensive)	~1 000	4 000	<1:1
V Cruz Farm San Luis, Pampanga (intensive)	~5 000	5 000	1:1
J Marin Farm San Luis Pampanga (intensive)	8 750	8 500	~1:1
R Alfonso Farm San Luis, Pampanga (intensive)	8 750	5 000	1.75:1
Harvest Moon Farm Candaba, Pampanga (semi-intensive)	~10 000	35 200	<1:1
D Maglanque Farm San Luis, Pampanga (intensive)	~25 000	43 750	<1:1
R Sevilla Farm San Miguel, Bulacan (semi-intensive)	3 600	3 360	1.07:1

Note: feed consumption and yield cells with no information (–) mean that data were not shared by these respondents; in these cases FCR were estimated by the farmers.
Source: Field survey (2010).

The feed conversion ratios (Table 12) varied from <1 to 1.7. Many FCR values are less than 1, and may not provide a true reflection of the feed performance. The low FCR recorded may have been due to the natural productivity in the systems, which provided nutrition to the fish over and above that which they received from the feed. The low FCR may also be attributable to poor record keeping, or inappropriate FCR calculations.

4. OVERALL ASSESSMENT OF FEED MANAGEMENT AND UTILIZATION

4.1 Conclusions

Applying the estimated gross returns that are based on feed/fertilizer inputs and fish yield, it seems that tilapia the feed utilization and management of breeding and hatchery operations are more cost-efficient when in intensive conditions. In contrast, cost efficiencies in pond and cage-based tilapia grow-out systems are similar; however, profitability could be further increased with improvements to feed management strategies.

Feed use is responsible for approximately 50–60 percent of operational expenses. In this regard, the possibility of achieving higher returns on investment would be greater if farmers adopted cost-saving strategies to minimize feed costs. In future, feed ingredient costs will inevitably continue to rise as the demand, and particularly that for imported feedstuffs (e.g. fishmeal), increases. Therefore, research programmes need to be coordinated to improve feed technologies and provide farmer training to improve feed efficiencies. Existing technologies, ranging from the formulation of farm-based feeds to the use of efficient fertilization and feeding strategies (Thakur *et al.*, 2004) are currently available. However, research and development institutions – particularly those with the additional mandate to promote technologies as such – need to disseminate and commercialize these technologies to the fish farmers. Another concern is the need to educate the farmers on the adoption of sustainable farming practices. Notably, when using formulated feeds, farmers should adopt best management practices that not only increase earnings but also minimize environmental impacts. The gradual destruction of the environment brought about by the negative impacts associated with intensive tilapia farming may reduce productivity, ultimately affecting profits. An initiative to promote environmentally sustainable aquaculture also needs to include the fish feed manufacturers. This sector has the responsibility of developing products that are both cost-effective and minimize their negative environmental impacts. With respect to research institutions, it is hoped that they will continue to receive support from both the national government as well as the private sector to improve and refine culture technologies, including nutrition. The research institutions should not only disseminate science-based technologies to farmers but also provide backstopping support in terms technical inputs to legislators, particularly with respect to forming regulations related to feed quality.

Recently, farmers have started to report production problems perceived to be associated with natural calamities and climate change (sudden temperature fluctuations due to El Niño); these are reported to be negatively affecting both breeding and grow-out operations. Such problems are seriously affecting stocks bred and reared in land-based facilities, especially in earthen ponds, and researchers need to focus on addressing these issues.

Finally, the three government agencies involved in feed regulation, namely BAI, BAFPS and FHS-BFAR, should ensure that feed manufacturers strictly observe aquaculture feed quality standards, and that the aquaculture practitioners adopt suitable feed management strategies (BFAR-PHILMINAQ, 2007). When strictly implemented, the guidelines/policies as proposed by these agencies will benefit the farmers.

4.2 Recommendations

In summary, the following recommendations are made to promote increased tilapia production through improved feeds, feed management practices and aquafeed-related regulations:

4.2.1 For farmers:

- Keep good records of all the activities on the farm – especially in terms of the type of feed inputs, feeding management, breeding and farming practices, fish yields, and other information pertaining to the husbandry schemes that result in increased fish production. This is to allow the farmer to determine the viability of the farm (both from technical and financial perspectives) and implement improvements as necessary to further optimize tilapia production at a minimal cost.
- Seek advice and adopt feed management innovations from trained technical people, such as aquaculture researchers and extension workers.
- Apply good feed management and husbandry techniques to improve yields.
- Actively seek and try improved industrial aquafeed products, as well as inexpensive raw materials for use as ingredients for farm-made feeds.

4.2.2 For technology developers/aquaculture researchers/extension workers:

- Develop low pollution, cost-effective diets.
- Promote the importance of acquiring skills on the production and use of farm-made feeds.
- Evaluate raw materials for feed ingredients that can be used as substitutes for expensive and imported feed ingredients such as fishmeal and soybean meal.
- Develop cost-effective feeding strategies that would improve production efficiencies.
- Guide government agencies in the formulation of guidelines for feed regulations.

4.2.3. For regulatory bodies (BAI, BAFPS and FHS-BFAR):

- Define their individual mandates to avoid overlaps in their respective regulatory functions.
- Strictly enforce the nutrient standards for aquafeeds in the Philippines.
- Create and implement standards for feed quality, such as feed digestibility, diet stability and FCR.
- Develop and promote the use of simple feed quality assessment methods at the farm level.
- Promote good feeding management practices to the farmers.
- Effectively and regularly monitor feed supply, feed prices and feed product standards in the aquafeed markets.

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On-farm feed management practices for Nile tilapia *(Oreochromis niloticus)* in Thailand

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ABSTRACT

This document describes the on-farm feed management practices used in the culture of the Nile tilapia (*Oreochromis niloticus*) in Thailand. A survey was undertaken to establish the feed practices used in pond grow-out systems, river-based cage systems, and hatcheries. Pond culture is common in Thailand, especially in rural areas. Almost all of the subsistence tilapia farms employ polyculture systems whereas most of the commercial farms practice single species all-male tilapia culture. Silver barb (*Barbonymus gonionotus*), snakehead (*Channa spp.*), hybrid catfish (*Clarias gariepinus* x *C. macrocephalus*), common carp (*Cyprinus carpio*), and some Chinese and Indian major carps are among the species used for polyculture. Almost all the farmers fertilize their ponds with either chicken manure and/or chemical fertilizers to enhance the natural productivity of the culture systems. Feeding is undertaken on a supplementary basis. Although good quality aquafeeds are available in Thailand, their high prices and the low price attained for pond-grown fish make their use currently uneconomic. The cheapest feeds and feed by-products available are used to minimize production costs, thereby maximizing profits. Almost all the farmers surveyed employed hand feeding twice per day, and generally reported FCR values of less than 1:1. However, as the fish receive a considerable amount of nutrients from the natural productivity in the ponds, the true FCR values accruing to the supplementary feeds are difficult to establish. The feeds/ingredients that are used are not of a standard quality in terms of nutrient composition and moisture which further exacerbates the problems associated with establishing accurate FCR values. In recent years, cage farming in rivers and canals has become a popular culture option. Almost all the cage farmers practice monoculture, using varieties of red or black Nile tilapia. Although commercial pellets are used, the feeds are normally of a low quality with a low crude protein level (~20 percent). On average, cage farmers feed three times a day, and attain FCR of 1.4–1.8:1, and growth rates of 2–3 g/day.

In terms of feed distribution, feeds and feed ingredients are transported in pick-up trucks by the farmers or delivered by the manufacturers/feed dealers. Farmers store their feeds in sacks in cool storage areas. Prior to feeding, the feeds are normally kept in large plastic buckets at the pond sites or at the riverbanks, and the quality of these feeds often deteriorates as a result of the high humidity and the extreme heat of the sun during the daytime. In general, raising tilapia using high quality commercial feeds is not profitable, and thus the selection of appropriate feeds is one of the most important decisions that farmers make in terms of ensuring the profitability of their farming operations. Training in feed production and improving their feed management practices is required to assist the farmers in increasing their profitability. This training should include the selection of feed ingredients, storage systems, and feed management practices. In this regard, the production and distribution of a training manual in local languages outlining best farming practices would be useful.

1. INTRODUCTION

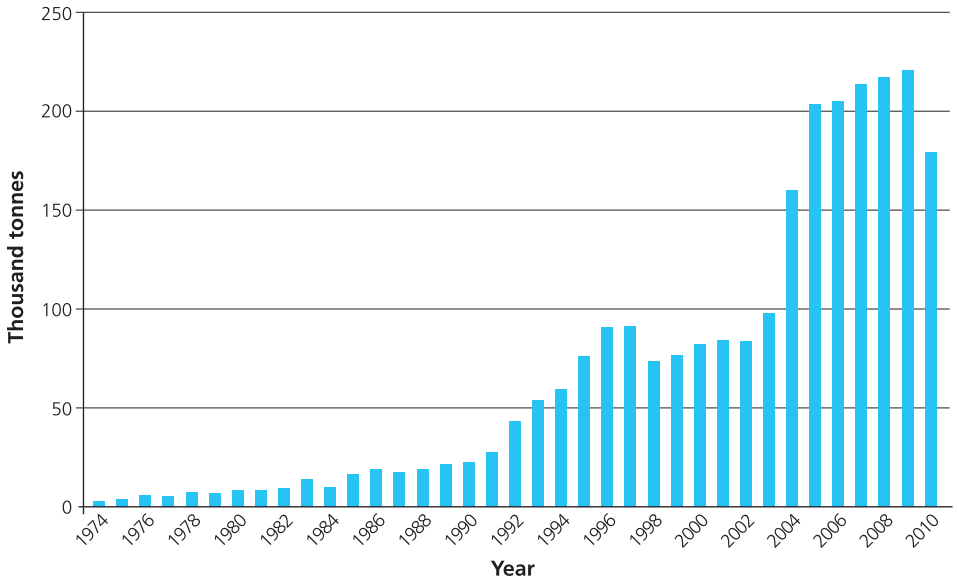
Nile tilapia (*Oreochromis niloticus*) were first introduced to Thailand in 1965 when 50 fry were imported (Pullin, 1998). These fish represent the founding stock for Nile tilapia culture in Thailand, and are popularly known as the 'Chitralada' strain. Since the 1960s, tilapia culture has expanded rapidly, and it is now the main fish culture species in the country. As tilapia grows well under adverse environmental conditions, it has become the culture species of choice for many poor farmers. Indeed some shrimp farmers started to culture the species in rotation with shrimp when production in that sector was impacted by disease in the mid-1990s. The Nile tilapia 'Chitralada' strain has been used as the founder stock for tilapia culture in many countries, including Bangladesh, Brazil, Cambodia, Laos, the Philippines, Myanmar, Nepal, and Viet Nam. Over the past two to three decades, broodstock, fry, and associated production technologies have been transferred to these countries.

Since the 1960s, other strains of Nile tilapia have been introduced into Thailand. For example, in the late 1990s, the Genetically Improved Farmed Tilapia (GIFT) strain and the red tilapia – a hybrid of Nile tilapia (*O. niloticus*) and Mozambique tilapia (*O. mossambicus*) have been introduced. At the same time, other red hybrid varieties such as Taiwanese red and the Malaysian red have been developed through selective and cross breeding programmes. The Thai Department of Fisheries (DoF) has also developed its own strain, known as 'Thai red'. The local name given by the His Majesty the King of Thailand, for red tilapia is 'Thapthim', meaning 'ruby'. The development of this strain provided a boost to the industry by increasing the price of the fish and, in this regard, many people consider 'Thapthim' as a premier tilapia product.

In, 2006, Thailand produced 2.8 million tonnes of fish and became the ninth world producer nation (FAO, 2009). In terms of export earnings (US$5.2 billion), the country became the third largest exporter of aquaculture products after China and Norway, and Thailand is now sixth in the world in terms of producing food fish from aquaculture (FAO, 2013). Annual per capita fish consumption in Thailand is about 35 kg, indicating that fish is an important dietary component for the Thai people (FAO, 2009). Aquaculture production has risen steadily since 1950, and in the past 20 years it has increased by approximately 800 percent (Bhujel and Stewart, 2007). In terms of freshwater production, more than 300 000 farmers currently culture fish in over 0.1 million ha. Over 97 percent of the total farming area comprises of ponds, and the remaining 3 percent comprise tanks, raceways, ditches and cages. Combined, the total Thai freshwater aquaculture production has reached about half a million tonnes per annum with the top five species being Nile tilapia (*O. niloticus*), hybrid walking catfish (*Clarius macrocephalus* x *C. gariepinus*), silver barb (*Barbonymus gonionotus*), freshwater prawns (*Macrobrachium rosenbergii*), and snakeskin gourami (*Trichogaster pectoralis*), respectively.

Nile tilapia, known as *Pla Nin* amongst the Thais, constitutes the largest production sub-sector, eclipsing hybrid catfish production in the mid-1990s. Although it was introduced to farmers in the field by the Department of Fisheries (DoF) in the mid-1960s, tilapia production did not significantly increase until 1990 (Figure 1). This was probably a result of a lack of production technologies, including breeding and feed management protocols. The increase in production coincided with the development of seed production systems, and notably the introduction of sex-reversal technologies. Once this technology was developed and commercialized, production exponentially increased. During this period, tilapia production surpassed catfish production to become the major culture species in the country. It has not been established why production remained stagnant between the mid-1990s and the mid-2000. However, it is possible that production levelled off as a result of a saturated domestic market and high production costs, which made the penetration of export markets problematic. Nevertheless, since 2004 production has increased, possibly as a result of the promotion of cage culture in rivers, reservoirs and canals, and notably the culture of red tilapia (Thapthim) under contract farming agreements. Recent estimates based on a market survey and seed production data show that total production has been underestimated at least by 50 percent (Belton *et. al*., 2009; Bhujel, 2009). The annual tilapia production reported in 2010 is over 179 000 tonnes (FAO, 2013); this is over 10 times more than the production level reported in 1987.

FIGURE 1
Total production of tilapia in Thailand (1970–2010)



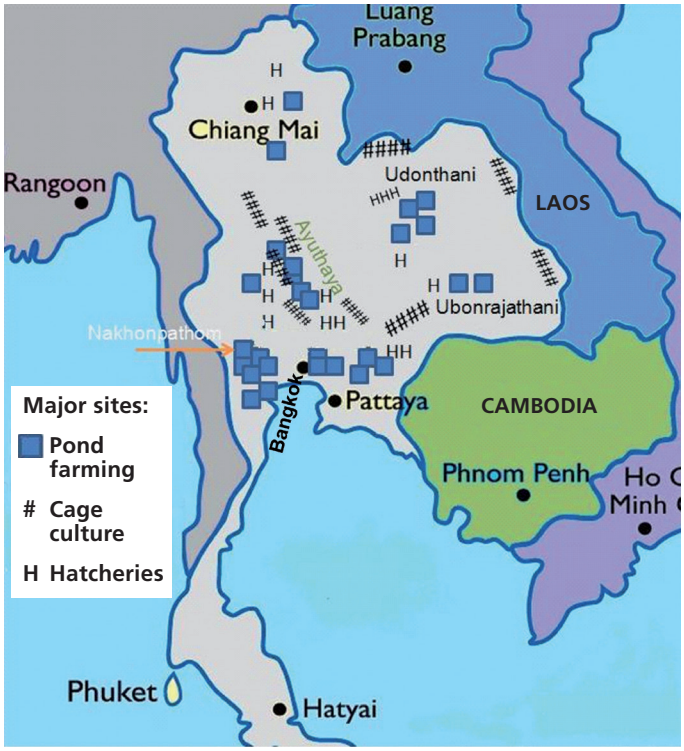
Source: FAO (2012).

2. CASE STUDY METHODOLOGY

2.1 Survey method

An interview survey was undertaken at a regional level in various parts of Thailand (Figure 2). Approximately one fourth of the respondents was met personally and interviewed using semi-structured questionnaires. Others respondents were contacted telephonically and interviewed using the same questionnaire. Information regarding the feeds and feeding management practices that are applied to broodstock and fry were derived from 13 tilapia hatcheries. Information pertaining to the

FIGURE 2
Map of Thailand showing the major sites of tilapia hatcheries, ponds and cages contacted/visited for the collection of information



Source: R.C. Bhujel.

Note: tilapia hatcheries (H), ponds (■) and cages (##) contacted/visited.

use of grow-out feeds and feeding methods was based on 60 grow-out farmers, 20 percent of whom were cage farmers. Among the pond farmers, the majority of farmers used polyculture systems. Almost all of the subsistence tilapia farms use polyculture systems, whereas most of the commercial farms produce single species all-male tilapia. Silver barb (*Barbonymus gonionotus*), snakehead (*Channa* spp.), hybrid catfish (*Clarias gariepinus* x *C. macrocephalus*), common carp (*Cyprinus carpio*) and some Chinese and Indian major carps are among those species used in the polyculture systems. In contrast, all the cage farmers practised monoculture, either of red (*Oreochromis niloticus* x *O. mossambicus*) or Nile tilapia (*Oreochromis niloticus*).

2.2 Description of the surveyed areas

Although tilapias are farmed throughout Thailand there are some clusters or concentrations of production systems in specific regions of the country. Tilapia culture is primarily concentrated in the inland areas, with shrimp farming dominating at the coast. The most common production system that is used in Thailand is pond culture. Either monoculture or polyculture systems using catfish and various carp species are used. Bangkok and the surrounding provinces, including Nakhon Pathom, Pathumthani, Ayuthaya, Suphanburi, Prachinburi, Chachoengsao, Chonburi and Samutprakan, are the main areas where tilapia farming has become a well-established commercial activity. These areas are particularly suitable for tilapia culture because:

- There is low land where abundant water is available throughout the year.
- There is warm weather throughout the year with temperatures rarely falling below 25 °C.
- There is a good market in Bangkok and the surrounding areas.
- There are good facilities in these areas including transportation, processing and packaging.
- Cheap feeds are available (e.g. restaurant wastes, wastes from chicken factory).

Other areas where tilapia farming has become common include the northeast of the country, in an area popularly known as Isan. The major provinces in this region include Udonthani, Uborachathani and Nongkhai. This region is considered the poorest region of the country, and various community development organizations are promoting tilapia as a mechanism to promote food security and reduce poverty. Although the region is in a drought-prone area, tilapia is currently grown in almost

every village; however, the majority of farmers have to wait until the rain starts to stock their fish. As one of the most popular destinations for tourism in Thailand, Chiang Mai also has a high demand for fish and seafood, and tilapia farming in this area is also expanding. Although, in comparison with the rest of the country winters are slightly cooler, tilapia can still breed and grow in this northern region.

In the late 1990s, cage culture systems were developed and they have now expanded to many parts of Thailand. These systems are primarily located along the banks of major rivers and canals. One of the most important rivers is the Chayophraya River and its tributaries that connect Bangkok to Chiang Mai. The cage systems are particularly popular in Pathumthani, Ayuthaya and Supanburi provinces. Another important river that has been used for tilapia cage farming is the Mekong River along the border with Laos, particularly in Nong Khai, Mukdahan and Ubonrajathani provinces of the northeast region.

3. MAJOR FINDINGS

3.1 Traditional fry production method and feeding

Mixed-sex tilapia seed are produced through natural spawning in small and medium earthen ponds. The production system comprises three basic components, *viz*. broodstock collection and management, natural spawning and fry collection, and the rearing of the fry in nursery ponds.

Broodstock are normally purchased from hatcheries that are known for the production of high quality fish. The fish are stocked at 3–4 fish/m^2 in small to medium sized broodstock rearing earthen ponds. Ponds size are normally between 1 000–1 600 m^2, with depths ranging between 1.0 to 1.5 m. Prior to stocking, all predator and other fish are eradicated using pesticides such as rotenone and potassium cyanide, and the ponds are limed at 250–500 kg CaO/ha. About a week after the liming process, the ponds are manured and fertilized with chicken manure at 800–1 000 kg/ha, and with urea and triple super phosphate (TSP) at 25 kg/ha each.

During the broodstock growth and conditioning period, some farmers use formulated or commercial feeds. These contain 25–30 percent crude protein. Feeding rates vary between 1–3 percent of body weight per day during the adult stage, and up to 10 percent at the younger stages of production. It is common that during rearing, seven to fourteen day old fish are fed to satiation and then placed on restricted rations thereafter. When formulated feeds are not available or are of dubious quality, the hatchery owners may elect to use alternative farm-made feeds. Typically these comprise mixtures of 60 percent rice bran and 40 percent soybean cake or 75 percent rice bran and 25 percent fishmeal. These feeds are fed at 3–5 percent biomass per day over two rations.

In the nursery ponds, the tilapia fry are reared using a two-stage process. In the first stage, fry are stocked in well prepared nursery ponds at 500–600 fry/m^2. Early fry are fed with powdered feeds that comprise a mixture of rice bran and mustard oil cake (1:1 ratio) at 12–15 percent initial body weight. The ration is fed over 3–4 feeds per day. The fry are reared for about 21 days in these ponds to attain an average weight of about 1 g. At this point some of the fry are usually sold directly to buyers, or reared in another series of nursery ponds at stocking densities of between 200 and 300 fry/m^2.

Second stage (or advanced fry) production produces larger fish over a further 40–60 days, These fish are reared at stocking densities ranging between 100–200 fry/m^2 in well-prepared nursery ponds. During this stage of production, the fry are fed formulated feeds and the feeding rate is reduced to 8–10 percent biomass per day. The fish are fed 2–4 times per day until fingerlings attain the average body weight of between 8–10 g each.

Concrete tanks are often used for tilapia seed production. The tanks that are constructed do not require large areas of land, and are therefore often located in the towns and cities. Tilapia breeding tanks are generally simple and smaller in comparison to the grow-out tanks. Normally farmers use rectangular tanks of various sizes – between 2.0–10.0 m long, 2.0–4.0 m wide, and with a depth of 0.8–1.0 m. Sexually matured broodstock weighing between 80–100 g each are stocked in the breeding tanks at a density of 3–4 fish/m^2, and at a sex ratio of 1 male to 3 females. Usually the breeders are replaced when they attain an average weight of 250 g or more.

A mixture of 60 percent rice bran and 40 percent mustard oil cake, or 75 percent rice bran and 25 percent fishmeal is fed to the broodstock at 3–5 percent of body weight per day. Feeding is undertaken twice a day. While mouth brooding the females do not consume artificial feeds, and thus feed rations are reduced during this period to minimize feed wastage and to maintain good water quality.

For the first week after mouth brooding, fry are stocked at 1 000–1 200/m^2 and fed with a high protein powdered feed containing at least 35 percent crude protein, and at 15–20 percent of body weight per day. Feeding is undertaken between 4 to 6 times per day. After a week, the density of the fry is reduced to 500–600/m^2, and feeding rates are reduced to 12–15 percent of body weight per day. After the second week, the density is again reduced, and the fry are stocked at 300–400/m^2, and fed at 10–12 percent of body weight per day. Once the fry attain a weight of 1 g, they are usually sold. Advanced fingerlings (20–30 g) may be produced by rearing for a longer period in tanks, and at stocking rates of 100–150 fry/m^2, using formulated feeds containing crude protein levels of approximately 30 percent for a further 40–60 days.

3.2 Mono-sex fry production and feeding

The techniques for producing high quality mono-sex tilapia fry on a large scale using hormonal sex-reversal was developed early 1990s at the Asian Institute of Technology (AIT). A series of research trials established the production techniques in hapas (suspended enclosures in water bodies). The process involved the collection of eggs, artificial incubation, the rearing of the larvae in trays, and sex-reversal using the hormone methyl testosterone. The technology spread throughout the country once a private hatchery farm successfully commercialized the technology. After continuous efforts to transfer the technology through public and private sector channels, the technology has spread all over the world, and now accounts for the production of an estimated two billion mono-sex tilapia fry per year (Bhujel, 2009). It has been estimated that Thailand alone produces over a billion fry per year using this technique; about one fourth of this is believed to be red tilapia. In Thailand there are over 40 private hatcheries and, according to a DoF staff member, every provincial fisheries station now has a tilapia hatchery using this technology. The technique is becoming increasingly popular in Bangladesh, Brazil, P.R. China, Indonesia, Myanmar, the Philippines, Viet Nam and several other countries. Assuming 60 percent of the stocked fry survive and are sold, nearly one million tonnes of tilapia (i.e. about one third of the global tilapia production) is produced using this technique per annum – this is sufficient to supply 60 g of high quality protein (of fish meat) twice a week to over 30 million people. Although, tilapia production in Thailand has been formally estimated at about 200 000 tonnes per annum, actual production is believed to be much higher, possibly 50 percent higher (Belton *et. al*., 2009; Bhujel, 2009); however, as most tilapia are sold in local markets and consumed at home, it is difficult to keep accurate records.

3.2.1 Breeding system and feeding management

Broodstock fish are a key element of the hatchery production process, and their quality and management affects the quality and quantity of seed production. A large-scale mono-sex tilapia hatchery farm supplying over 10 million fry per month maintains

FIGURE 3
Breeding hapas and egg collection

COURTESY OF FAO/R.C. BHUJEL.

a large number of brooders, working broodfish, and new batches for replacement every two years. Feed represents the major production cost for the hatchery operators. The production of mono-sex tilapia is undertaken using hapa-based systems. For example, on the Nam Sai (Prachinburi) and other large farms, breeders are stocked in large nylon hapas of 120 m^2 (24 m x 8 m, Figure 3) and covered with bird nets to deter predation and to reduce heat stress. Some other farms, such as AIT (Pathumthani) and the hatcheries in Udonthani (Provincial hatchery, Agriculture College, and Isan Aquatics), use smaller size hapas (40–60 m^2). Depending on the scale of the operations, the farms may maintain up to 100 000 broodstock. Males and females are stocked at ratios of 1:1 or 1:2 (male:female) and at various densities. Typical broodstock stocking densities are 2/m^2 in ponds, 6/m^2 in hapas and 10/m^2 in tanks.

Feed management practices need to be optimized in order to supply the nutrient requirements of the broodstock, maintain water quality and keep production costs low. Feeding up to 25–50 percent of satiation produces more eggs (e.g. *O. mossambicus*, Mironova, 1977). Applying supplementary feeding regimes, Nile tilapia fed at 1 percent of body weight per day produce more seed than fish fed at 0.5 percent or 1.5 percent biomass. In a study with *O. niloticus* (Bhujel, 1999) in hapas, a feeding rate of 1.4 percent of body weight per day was more productive than feeding at 0.7 percent of body weight per day; however, on the higher ration, the broodfish grew too large to handle within 3–4 months. A feeding rate of about 1.0 percent of body weight per day is suitable for tilapia broodfish in greenwater production systems, whereas in clearwater production systems a feeding rate of 2.0 percent of body weight per day is optimum. In greenwater systems, a feeding frequency of twice per day as opposed to once per day produces more seed when the feed ration is reduced (0.5 and 1.0 percent of body weight per day), but less seed were produced when the ration was increased to 1.5 percent of body weight per day. Tilapia females incubating eggs and fry in their mouths do not feed. However, on cessation of mouth brooding, they compensate for the restricted feed intake. Higher feeding rates for the first 2–3 days after seed harvesting followed by lower feeding rate may prove to be an economical feed management practice (Bhujel, 2000). Alternatively, it is possible that for the first one to two days after each seed harvest, feeding rates of twice or thrice a day followed by once a day thereafter might produce similar results. As tilapias do not eat early in the morning, feeding is undertaken after 8 am, followed by a second feed before sunset.

Similarly, small pellets or high-energy rations with low feeding rates seem to produce better results than large pellets or high feeding rates; this could possibly be due to differentials in feed intake and nutrient utilization. If they are available and affordable, floating pellets are recommended for the broodstock. Resource-poor farmers may simply use rice bran in combination with oil cakes and/or fishmeal. These feeds usually contain between 25–30 percent crude protein, 12 percent moisture, 4 percent fibre and 8 percent lipids (Bhujel, 2001; Bhujel *et. al.*, 2001).

Prior to broodstock stocking, ponds are drained and sun-dried for at least a week, and limed at 500–1 000 kg per ha. Ponds are fertilized with urea and TSP at 28 kg N and 14 kg P/ha. This is undertaken on a weekly basis to enhance the natural productivity of the ponds and thus provide additional supplemental feed to the broodstock. Some hatcheries, such as Chamnoeng Farm in Chiang Rai, use tanks (100 m^2 stocked with 200 females and 100 males). If the broodstock are in clearwater systems, they are fed commercial feeds (35 percent protein) at 2–3 percent body weight per day, twice daily. It is interesting to note that recent unpublished research shows that using greenwater systems with supplementary feed produces better egg production compared that achieved when using commercial pellets in clearwater systems (no fertilization in ponds).

3.2.2 Broodstock fry rearing and feeding

Broodstock are normally replaced after 2–3 years when they grow to over 400 g. This is due to the fact that large fish are difficult to handle while collecting eggs from their mouths. Depending upon the scale of operation, new batches of brood fry have to be prepared to replace breeding stock. During broodstock rearing, most hatcheries in Thailand use mixtures of rice bran and fishmeal, although some hatcheries use commercial pelleted feeds. Table 1 provides a summary of the procedures used for broodstock fry rearing and maturation.

TABLE 1
Normal procedures for broodstock rearing and maturation

Month	Stage	Stocking density (number/m^2)	System	Feeds and feeding
0–2	1st nursing	1 000	Hapa	Rice bran and fishmeal (3:1), 5 times daily, *ad libitum*
2–4	2nd nursing	200	Hapa	Rice bran and fishmeal (3:1), 5 times daily, *ad libitum*
4–6	Maturation	1	Pond	Same as above or pellets (~30% CP), twice daily, *ad libitum*

Source: Bhujel (2012).

3.2.3 Egg incubation and larval rearing

Harvested eggs are separated according to their five developmental stages:

- Stage I: freshly laid eggs, normally yellow in colour.
- Stage II: 1-day old embryos with a reddish colour, two small eye spots may be seen.
- Stage III: 2-day old embryos with protruding eyes and a small tail.
- Stage IV: 3–4 day old yolk-sac fry after hatching.
- Stage V: Well developed swim-up fry.

Stage I–III are incubated artificially in plastic, fibreglass or simple plastic glass jars supplied with clearwater that has been treated, either using slow sand filtration, UV treatment or alternative filtration systems. When the eggs hatch and mature to stage IV (or are collected from the broodfish), they are moved to shallow trays. Most hatchery operators do not feed during these stages. However, some start feeding hormone-laced feed (see 3.2.4) for about a week as the fry start to swim-up i.e. Stage IV. The rationale is to habituate them to external feeds before they go to the sex-reversal hapas/tanks.

3.2.4 Sex-reversal and feeding management

The early nursing of fry is normally undertaken in hapas in ponds – this method represents the cheapest production paradigm. However, some hatchery operators use tanks fitted with re-circulation systems. Fry are treated with a hormone (17α-methyltestosterone, hereafter referred to as MT) to produce all-male populations. The fry at their first feeds are fed for 21 days on a mixture of fishmeal and MT hormone

five times a day. This process produces phenotypically all-male populations, which prevents breeding in grow-out systems, and results in growth rates that are approximately 20 percent faster than those of untreated populations (comprising 50 percent females). Sex-reversal feed is prepared (Figure 4) according to the following protocol:

- 60 mg of 17µ-methyl-testosterone (MT) is mixed with 1 kg of fishmeal and 10 g of vitamin C.
- As the hormone is insoluble in water, ethyl alcohol is used as a solvent. Normally a stock solution of 5 g of hormone in 10 litres of ethyl alcohol is prepared, and stored in a refrigerator. The stock solution can be stored for 6 months.
- The hormone is added to the feed by adding 120 ml of the stock solution and 120 ml of fresh alcohol and mixing.
- The alcohol is evaporated off by spreading the mixed feed under shade for about an hour. The feed is dried under mild sunlight as the efficacy of the hormone declines in the presence of high heat and bright light.
- After drying, the feed is packed in plastic bags or kept in the container with tight lid and stored in a room at low temperature.

Tilapia fry accept feed immediately after yolk-sac absorption. There is no need to feed live feeds such as algae, *Artemia* and rotifers. Normally, tilapia fry are fed with fishmeal, rice bran or oil cakes separately or in combination, either in a powdered form or as dough. However, feeding practices depend on the production systems in use. Some commercial hatchery operators in Thailand use shallow trays in re-circulation systems and feed fine fishmeal (~60 percent CP) to supply dietary nutrients, and to initiate/habituate the fish to feeding on artificial feeds. This is done so that when they are transferred to hapas in ponds, they readily accept pelleted feeds. This practice ensures improved food intake and the ingestion of sufficient hormone to ensure sex-reversal. Feeding larvae after yolk-sac absorption appears to be beneficial to the fry; however, accumulated uneaten feed can pollute the system, necessitating frequent cleaning. The swim-up fry reared in recirculation systems are transferred to fine mesh hapas suspended in greenwater ponds.

To achieve sex-reversal, the fry are stocked at a density of 5 600–6 000 fry/m² in hapas installed in ponds/tanks (Figure 5), and are fed with the MT mixed feed at 70, 150, 250 and 420 g/day for 30 000 fry (in 5.4 m²) during the periods (days) 1–5, 6–10, 11–15 and 16–21, respectively. A total of 4.87 kg of MT feed is required to sex-reverse 30 000 fry. The feeding rates range from about 30 percent of the fry biomass per day at the beginning of the process to about 10 percent at the end. Fry are fed 5 times a day, normally at 08.30, 09.30, 11.30, 13.30 and 15.30 hours. The size of the hapas that are used during the 21 day hormone treatment depends on the scale of production. The smallest hapas are 5.4 m² and the largest 20 m². Hatchery operators who do not practice sex-reversal, feed their fry

FIGURE 4
Locally designed feed mixer with 15 kg capacity for sex-reversal feed production

COURTESY OF FAO/R.C. BHUJEL.

FIGURE 5
Feeding sex-reversal feed to tilapia fry reared in a hapa using a bamboo stick

COURTESY OF FAO/R.C. BHUJEL.

with a mixture of rice bran and fishmeal (2:1 or 3:1). Nursing the fry normally begins when the fry attain a weight of 0.2 –1.0 g. While many farmers feed rice bran alone 4–5 times daily, others rely on natural food enhanced with organic/inorganic fertilizers, or feed small pellets prepared for catfish or shrimp.

Good quality (high protein /palatability) fishmeal is used to promote feeding and ensure that the required level of hormone intake is attained. Local Thai fishmeal is cheaper (35 Baht/kg[1]) but it is lower in quality than imported products. The use of the local fishmeal generally results in a lower percentage of males. Fishmeal imported from Peru or Chile has been found to be of a suitably high quality and results in a high percentage of males. However, the imported fishmeal is relatively expensive (38 Baht/kg), and can often only be sourced in bulk (27 tonnes/container) – this often makes it unavailable to the smaller hatcheries. As a result, hatchery operators in Thailand are trying to identify alternate, low-cost feeds. In this regard, silkworm pupae were found to be a good fishmeal replacement; however they are only available in small quantities, and are thus only a partial solution. Similarly, some hatcheries use a high quality shrimp starter feed with 40 percent crude protein (42 Baht/kg); while the price of this feed is even higher than the imported fishmeal, it is readily available in the local market. This suggests that feed price is not the major factor in deciding what feed to use during sex-reversal, but rather that quality and availability are the key determinants.

3.2.5 Nursing/holding

Grading fry is very important in the latter stages of the fry production process, as it minimizes cannibalism related mortality and the development of dominance hierarchies. The first grading is undertaken after one month of hatching, followed by a second grading one week later, or a few days prior to sale. Fry are usually grouped into 3–4 size categories – small, medium, large and very large. The fry nursing period ranges from a few days to a month or so, and is dependent upon the demand for fry. During nursing, fry are kept in hapas at a density of 1 000–2 000 fry/m^2. The size of hapas range from 20 to 120 m^2, depending upon the scale of the operation. On some farms, fry are fed a mixture of rice bran and fishmeal (2:1 ratio, Table 2), 4–5 times a day and at 25–50 g/m^2/day. In contrast many farms use small floating pellets.

TABLE 2
Simple farm-made feed for tilapia nursing used by Nam Sai Farm, Thailand

Feed ingredients	Proportion (%)
Fishmeal	33.3
Rice bran	66.7
Total	**100.0**

Source: Field survey (2010).

[1] US$ 1 = Baht 32.5

Small (<2 cm) fry are susceptible to predation by other fish and birds. They are also less tolerant to poor water quality, which is a common feature in ponds that are fertilized with organic manures. The first month of the production cycle is crucial to survival, and if the fry can be nursed for at least a month before stocking them into the grow-out ponds, their survivorship can be increased significantly. The following guidelines are commonly used during fry production:

- Cages or hapas in ponds, reservoirs and lakes are ideal for nursing. The systems must be well protected from birds and other predatory fish or animals.
- Smaller ponds (50–500 m^2) are prepared, drained and dried completely for at least a week. Ponds are limed at 500–600 kg/ha, and filled with the predator-free water.
- A week before stocking the fry, the ponds are fertilized with urea and TSP to promote natural productivity. After fertilization, uneaten feed and their excreta will maintain pond productivity. Excessive productivity (greenwater) is undesirable during nursing, and therefore organic manures are not applied to the nursery ponds.
- The stocking density applied to nursing fry is 500–1 000 fry/m^2 in hapas/cages, and 100–200 fry/m^2 in ponds.
- Fry are fed floating pellets or a mixture of rice bran and fishmeal (2:1), 2–4 times a day, and at 5–10 percent of body mass per day, or to satiation.
- For convenience purposes, some tilapia hatchery operators use small catfish pellets – however, these pellets are often too large for the fry to ingest, and need to be crushed.
- The nursing period normally lasts for one month. During this period fry attain a weight of 1 g which is large enough to stock into the grow-out ponds.
- Farmers time their fry purchases according to their production cycles and take into consideration nursery production and fry availability, the preparation of the grow-out pond and fry stocking times. The farmers purchase their fry one to two weeks prior to the harvest of the grow-out pond, as it takes at least two weeks to prepare (drying, liming, fertilization and filling) a pond during which fry are nursed in small ponds or hapas.

3.3 Grow-out and feeding

Tilapia culture practices throughout the world are varied and are probably the most diverse for any cultured species. Tilapia can be cultured at different scales and densities, depending on the economics of the operations and the availability of resources. For example, tilapia can be cultured in backyard and/or home garden ponds to supplement incomes and as a source of food security or, alternatively, on an industrial scale in large intensive commercial farms.

From a nutritional perspective, one of the advantages of tilapia culture over other culture species is that it is a low trophic feeder. Most tilapia are omnivores, feeding on algae, aquatic plants, small invertebrates, detritus and the associated bio-flocs (Bowen, 1976; 1982). They are also somewhat opportunistic in their feeding behaviour, and are able to utilize many disparate food sources. This is an important benefit to farmers as the fish are able to make use of nutrients arising from the natural productivity in the culture systems, and this helps to reduce feed costs. They can also be cultured in extensive systems, and remain entirely dependent on natural productivity to provide their nutrition (AIT, 1994).

In extensive culture systems, tilapia are grown at low densities, consume algae and detrital matter, and are not fed artificial feeds. In intensive systems, tilapias are fed a formulated feed that includes a high percentage of plant proteins. Complete formulated feeds are used in culture systems that have no capacity to produce natural feeds – such systems include intensive water re-circulating systems, cages placed in water bodies that have low productivity, and high density pond systems that are unable to provide

sufficient natural productivity to supply the nutritional requirements of the fish. Supplemental diets, as opposed to complete diets, are designed to provide only a portion of the nutritional requirements of the fish, and when they are used, it is assumed that the fish will obtain the remaining portion of their feed requirements from the natural productivity of the culture system. Supplemental diets are usually much less expensive than complete diets, and are typically low in protein and high in carbohydrates. Some supplemental diets serve dual purposes – to supply nutrients directly to the fish, and to fertilize the pond waters, thus enhancing natural food production.

Commercial feeds are used as supplementary feeds in Thailand as their use as complete feeds provides limited profits. Feeds prepared for catfish and carps are commonly in use in tilapia culture. Alternative cheap feed sources have been assessed (e.g. fruit and vegetable wastes, crop by-products, leguminous fodders and aquatic plants). Among these, duckweeds (*Lemna* sp.) grown on-site, have been found to provide a suitable tilapia feed that can be fed at 3–5 percent body weight per day (dry weight basis) and produce fish of up to 100 g. However, a combination of duckweed and formulated pellets produces larger tilapia and at a relatively low cost (AIT, 1994). Several researchers have tried to test alternate vegetable proteins such as oil seed meals as fishmeal replacements; however, the growth attained with these materials is inferior to fishmeal. Despite this, many can be used as partial fishmeal replacements – often up to 50 percent of the fishmeal can be replaced without compromising growth. Commonly used fishmeal replacements include water hyacinth, fish silage, poultry by-product meal, feather meal, and meat or bone meals.

Attempts have been made to produce large tilapia across a number of culture systems – large tilapia fetch higher prices in both export and domestic markets. In ponds, it has been demonstrated that a combination of applying both feed and fertilizers as opposed to the use of either feed or fertilizer alone, is the most efficient way to produce large (500 g) tilapia (Diana, Lin and Jaiyen, 1994. In this regard, a similar study demonstrated that the most profitable way to grow large tilapia was to use greenwater systems until the fish were 100 g, followed by supplementary feeding (Diana, Kohler and Ottey, 1988).

Recently, Thai farmers have started to grow both black and red tilapias in cages along the borders of rivers, lakes, reservoirs and the coastline. To maximize growth, formulations containing 25–35 percent crude protein are fed *ad libitum*. These fish generally receive premium prices (US$1–2/kg), especially in the north and north-eastern parts of the country. Restricted feeding is recommended when the fish are cultured in ponds, as the tilapia can utilize the natural productivity in the pond waters. In terms of determining an appropriate level of restricted feeding, a study at AIT demonstrated that feeding Nile tilapia at 08.00 hours once-a-day resulted in low yields when compared with feeding twice or thrice daily. As there was no difference between the latter two options, twice daily is deemed the most economic feeding regime for this production scenario.

In semi-intensive culture systems, over 90 percent of pond farmers practice polyculture utilizing natural food enhanced through fertilization (Belton *et al.*, 2009). Although a large majority of farmers still apply semi-intensive technologies, tilapia farming is rapidly becoming intensified, especially in cages in canals, rivers and reservoirs. These systems now contribute approximately one-third of the total production of this species in Thailand.

3.3.1 Pond culture

Tilapia pond culture practices are, in almost all cases, undertaken under static conditions, where water is only changed between grow-out cycles, and aeration is rarely used. In a normal pond culture system, both the initial investment and variable production costs are low. This makes the system affordable for poorer farmers in rural communities. Most of the pond culture systems employ semi-intensive technologies

using fertilizers and supplementary feeds. In this way, ponds produce low-cost fish that contribute to national food security. Other forms of livestock production can also provide sources of nutrients for tilapia farming (Figure 6). Over the past decade, low and high-tech culture systems have been developed by farmers and corporate groups alike. In this regard, small-scale farmers have started to introduce tilapias into their traditional carp polyculture systems. At a larger scale, entrepreneurs are now exploring ways to farm tilapia for the international markets using relatively high-cost intensive culture systems and complete feeds (Edwards, Lin and Yakupitiyage, 2000).

FIGURE 6
A pig shed by the side of a pond (left) and a chicken house above the fish pond (right); uneaten pig and chicken feed and litter represents cheap sources of nutrients for the fish

COURTESY OF FAO/R.C. BHUJEL.

Pond culture is the most popular method of growing tilapia in Thailand (Belton *et al.*, 2009). The pond systems in use range from extensive systems, using only organic or inorganic fertilizers, through semi-intensive systems, using fertilizers and supplementary feeds, to intensive systems that use high protein feeds, aeration and water exchange. The major drawback to pond culture is the high level of precocious breeding that can occur when mixed-sex tilapia are used. The problem arises when the juvenile tilapia from the precocious breeding compete for food with the adults. The original stock becomes stunted, yielding only a small percentage of marketable fish of 400–500 g or more. In mixed-sex populations, the weight of recruits (derived from the precocious breeding) may constitute up to 70 percent of the total harvest weight. In terms of pond sizes, ponds tend to be shallow (1–1.5 m), and range between 0.1 ha and 5 ha. Farm sizes generally range from 1 ha up to over 20 ha.

Many farmers still grow mixed-sex tilapia fry because they are approximately one third of the price to produce than mono-sex fry (Bhujel and Nadtirom, 2002). Most farms using mixed-sex fry are small, use low inputs, and primarily produce for home consumption, with some fish being sold in the local market. In Central Thailand, a recent estimate showed mixed-sex culture accounts for up to 20 percent of production (Belton *et al.,* 2009). Normally, the tilapia are stocked with other species (e.g. carps, catfish, snakeskin gourami), and they are harvested before or soon after they reach sexual maturity. This practice is designed to minimize the effects of precocious breeding. However, the practice restricts the culture period and the size of fish that can be harvested. Nevertheless, this is the cheapest production method, and it is used in instances in which the size of the fish is not of major importance. In these systems, the tilapia are usually stocked at low densities to reduce the competition for food and to promote rapid growth. Approximately one month-old, 1 g fry are stocked at 5 000 to 15 000/ha in grow-out ponds for a 4 to 5-month culture period. Newly

hatched fry are used, because older, stunted fish, such as those held over winter, will reach sexual maturity at a smaller, unmarketable size. Supplemental feeds containing 25 to 30 percent crude protein are generally used. At harvest, average weights range between 200–250 g, and total production is approximately 3.8–7.8 tonnes/ha/cycle. The fish are stocked at 20 000–30 000/ha, and two production cycles are normally undertaken per annum. In general, farmers prefer to stock larger fingerlings (5–20 g) as they are hardier, resulting in higher survival and production rates.

Over 80 percent of the farmers culture mono-sex tilapia because they grow faster than mixed sex fry, and remain uniform in terms of size distribution. Mono-sex populations grow to around 500 g in 4–6 months and up to a kilo in 8–10 months. Mixed-sex populations normally reach 200–300 g, whereas larger tilapias (500 g–1 kg) can be harvested from mono-sex populations. Mono-sex populations are mostly produced by collecting the fry, incubating them as larvae, followed by a 21-day hormonal treatment to ensure that over 99 percent of the fish are males. The technology was refined and commercialized by AIT (Little, Turner and Bhujel, 1997; Bhujel, 2009).

Females always use substantial amounts of energy for egg production, and do not eat when they are incubating eggs. Male mono-sex culture permits the use of longer culture periods, higher stocking rates and fingerlings of any age. Currently, mixed-sex tilapia culture is in decline, and farmers are moving towards mono-sex tilapia culture to produce larger and more uniform sized tilapia. High stocking densities reduce individual growth rates, but yields per unit area are greater, and if growing seasons can be extended it is possible to produce fish weighing 500 g or more. Typical survival rates for all-male tilapia culture systems are around 90 percent, or greater. However, one disadvantage of male mono-sex culture is that female fingerlings are discarded – this problem has been overcome by producing sex-reversed male tilapia fry through hormone treatments. The production of mono-sex male tilapia fry represents a significant breakthrough in tilapia culture. The technology was developed in Thailand, and is now being transferred all over the world. However, the main drawback of mono-sex tilapia culture is its higher cost. In this regard, mono-sex tilapia is useful for commercial farms, but remains costly for poor small-scale farmer. The stocking densities and culture methods applied to mono-sex male culture depend on the economics of the farming operation. As stocking density increases more investment is required for feed and its procurement and management. Depending on the intensification of the culture methods, the range of stocking densities varies between 18 000 and 50 000 fry/ha with production varying between 5 000 and 10 000 kg/ha accordingly. Generally, 18 000 fish/ha represents a common stocking density in central Thailand, while higher stocking densities (resulting in smaller sizes at harvest) are generally applied in the north and northeast of the country where the price of the fish is higher. Table 3 presents recommended farming techniques for mono-sex populations (Bhujel, 2012).

TABLE 3

Recommended mono-sex tilapia farming techniques and production in Thailand

Stocking density (numbers/ha)	Rearing techniques	Amount of feed (kg)	Expected production (kg/ha)
18 000	Pond fertilization only	–	3 000
25 000	Pond fertilization only + limited feeding	–	5 000
31 000	Fertilization and feed for last 1 month	1 800	6 250
37 000	Fertilization and feed for last 2 months	3 750	7 500
44 000	Fertilization and feed for last 3 months	5 600	8 750
50 000	Fertilization and feed for last 4 months	7 500	10 000

Source: Bhujel (2012).

It was established that while many farmers lack training or guidance in feed management practices, they often attempt to minimize feed costs. The survey demonstrated that all the farmers feed in the morning, and only once a day. All the farmers use, and encourage others to use, chicken manure as the cheapest way of enhancing the natural productivity of their ponds. The rate of application was reported to vary between 63 kg/ha and 2 500 kg/ha (average 86 kg/ha). The price of chicken manure ranges from 0.4–1.6 Baht/kg (US$0.01–0.05). Farmers normally do not use pelleted feeds as they are deemed too expensive. The price of pelleted feeds ranges between 15–20 Baht/kg, and in some cases can be higher. Usually, farmers avoid commercially produced feeds and select the cheapest feeds available, which usually cost less than 15 Baht/kg. It was established that almost all the pond farmers use maize meal as a supplementary feed. Currently, maize meal costs less than one-third of the formulated feeds (6.0–6.5 Baht/kg; US$0.18–0.20). Locally available rice bran, costing 7.5 Baht/kg, is also used as a supplementary feed. Some farmers were found to use left-over or waste chicken feeds which cost 4 Baht/kg. However, this option is not always available. One farmer reported using food wastes from restaurants which could be procured for less than 1 Baht/kg.

Feeding and fertilization management protocols are presented in Table 4. Farmers generally produce 3–8 tonnes of tilapia per ha over a grow-out period of 8–9 months. The final sizes of fish vary greatly, and range from 300 g to 500 g or larger.

TABLE 4

Results of a survey on tilapia pond-based farms in Thailand: grow-out period of 8–9 months

	Average	Minimum	Maximum
Farm size (ha)	12.2	1.9	24.0
Stocking density (fry/m^2)	2.36	1.88	3.13
Yield (tonnes/ha)	6.1	3.8	7.8
Amount of feed (kg/ha/day)	128	39	375
Use of chicken manure (kg/ha)	866	63	2 500
Feed price (Baht/kg)	12	7	20
Sale price of fish (Baht/kg)	32	18	37

Currency: Thai Baht 32.5 = US$1.

Source: Field survey (2010).

Various forms of polyculture are practiced in Thailand. For example, mixed-sex Nile tilapia are grown in fertilized ponds with carnivorous fish such as the snakehead (*Channa* sp.) and catfish (*Clarias* sp.). The predator fish feed on the tilapia recruits that are produced as a result of precocious breeding, and this enables the original stock to attain a larger size. The level of predator fish must be small, normally comprising <1 percent of the population, and they are stocked when the tilapia begin to breed. Tilapia polyculture with carps is also common in Central Thailand where 80 percent of farmers surveyed have adopted this farming practice (Bhujel and Nadtirom, 2002). Silver barb (*Barbonymus gonionotus*), often called Thai carp, is one of the preferred species as it is attractive, easy to breed, serves as a water quality indicator, and is widely consumed as fermented or processed fish. Rohu (*Labeo rohita*) was found to be used by about 20 percent of the tilapia farmers. The reason that polyculture systems have been developed is that they utilize the various natural foods available in ponds, thereby increasing productivity. The practice also enables farmers to supply a variety of fish to the consumers. Mono-sex tilapias are also cultured in polyculture systems. A typical polyculture production scenario is presented in Table 5. The scenario is designed for a

5 ha pond in Pathumthani Province, central Thailand. Under this production paradigm, the farmers grow the fish for an 8 month period, feeding maize meal (6.5 Baht/kg; US$0.20). Occasionally, farmers will use left-over or waste products from chicken feed factories, where the wastes can be purchased for only 4 Baht/kg. Applying these feed resources, a total production of 20–30 tonnes of fish is possible from a 5 ha pond per crop. Such a system would produce a profit of approximately 1 million Baht (approx. US$30 000).

TABLE 5
Typical polyculture stocking in a large pond (5 ha) in central Thailand

Species	No. of fry/fingerlings
Nile tilapia (*Oreochromis niloticus*)	100 000
Silver barb (*Barbonymus gonionotus*)	10 000
Rohu (*Labeo rohita*)	3 000
Grass carp (*Ctenopharyngodon idella*)	1 000
Common carp (*Cyprinus carpio*)	1 000
Total	**115 000**

Source: Field survey (2010).

Other polyculture systems comprise tilapia and freshwater prawns (*Macrobrachium rosenbergii*). In such systems the survival and growth of tilapia and prawns are independent, and supplemental feeding is only supplied for the fish. The prawns, which are unable to compete for the feed, utilize waste feed and the natural productivity of the pond waters. The prawns are stocked at 1–2 g at 10 000–90 000/ha. Typically, a density of 20 000 prawns/ha is used to obtain a high percentage of market sized prawns (>25 g), and yields of about 600 kg/ha are attained. Tilapia are stocked at densities ranging from 2 000 to 4 000 per ha.

3.3.2 Cage culture

Around 1997, cage culture was introduced to Thailand by the Charoen Pokphand (CP) Group of Companies. Approximately one-third of the tilapia produced in Thailand is currently derived from cage culture. Culturing mixed-sex populations usually results in relatively slow growth rates and high feed conversion ratios (FCR), e.g. ±1.8:1. In contrast, faster growth rates and lower FCR (±1.4:1) are attained using mono-sex populations and thus, for production efficiency reasons, the culture of mono-sex populations is the preferred option (Belton *et. al*., 2009). The difference between the FCR attained using these two types of systems equates to a difference of 10 Baht/kg (US$0.31) in production costs.

The CP Company operates specialized hatcheries to produce red tilapia 'Thapthim' fry, which they supply to 'contract farmers'. The company provides the farmers with seed, feed, and loans for cage construction. The farmers under contract form associations in each production area. These associations assist in buying seed in large quantities and at cost effective prices, and provide communal labour during harvesting. Red tilapia culture has been heavily promoted by the company along the Chaophraya and Bangpakong rivers. In addition, culture areas have expanded to reservoirs and irrigation canals. In Pathumthani (Klong 13), about 45 km north of Bangkok, an average farmer would have 6–7 cages, referred to as a unit. However, some other farmers may have 30 or more cages. The investment cost for one cage is approximately 4 000 Baht (approx. US$125). Plastic drums are used for buoyancy, and the cages themselves are made of wood. Most cages are 54 m^3 (6 m x 6 m x 1.5 m). The stocking

rates for this size of cage would be 20 000 fry per cage. The cages are arranged in such a way that one unit is isolated and used for growing fry to fingerlings, a process that usually takes 45 days. The fingerlings are then transferred into the production cages at a density of 2 800 for 120 days prior to harvesting. Typically, yields range between 1.8–2 tonnes per cage over a 6-month production cycle. Survival is normally over 95 percent. On completion of the grow-out cycle, the CP Company buys the fish from the farmers, deducting their loans from the value so that the farmers receive the difference as their net earnings. Farm-gate prices for tilapia grown in Thailand are in the region of 35–39 Baht/kg (US$1.08–1.20). However, the red tilapia sells for 82 Baht/kg (US$2.52). Fry are sourced from specialized hatcheries, and most sites are well linked by good roads to markets. Commercially manufactured feeds are generally used in cage culture production systems.

Cage culture has been introduced along the Mekong River on the border between Laos and Thailand. Cage sizes on the Mekong River tend to be similar to those found in Canal 13, Pathumthani Province, i.e. 45 m^2 (5 m x 6 m x 1.5–2.0 m depth). Stocking densities of 80 fish/m^3 are used, whereas in Viet Nam density may be as high as 100 fish/m^3. [In Viet Nam, higher stocking densities are feasible as the water flow in their rivers is faster, and thus water quality can be maintained.] Cages are stocked with 30–50 g fingerlings which are grown out over a 5 month period. Two crops per annum are produced using this system. The fish are fed good quality floating commercial pellets containing 30–35 percent crude protein, and at 2–5 percent of body weight per day. The price of caged tilapia is around 50–60 Baht/kg. Feed prices are approximately 20–25 Baht/kg. Due to these feed costs, FCR that are above 1.5:1 would make these ventures unprofitable. Cage production systems produce up to 2–2.5 tonnes of fish per annum, and produce fish ranging from 900–1 000 g. Fish are harvested and lifted from the cages to the roadside by a motorbike connected to a pulley. Harvested fish are transported by truck, and normally sold fresh in the domestic market.

Pond-based cage culture is currently being trialled in Thailand. The move to culturing the fish in ponds is a result of some large-scale mortalities that occurred in 2004 in the Chaophraya (in Ayuthaya/Pathumthani area) and Bangpakong Rivers (in Prachinburi province). According to the local farmers, the first mass mortality was caused by the release of large quantities of sugar/molasses from a boat that sank in the Chaophraya River. The second event was caused by the release of a large amount of pesticides that had previously accumulated in the river sediments. The chemicals were released during the sudden opening of a canal sluice gate. Both cases affected hundreds of families, and thus both private companies and farmers are trying to reduce their production risks by placing cages in large ponds instead of river systems. An example of cage-based pond culture was assessed on a farm in Chiang Rai (northern Thailand), where the farmer had 1–2 ha ponds, and used 32 m^3 cages (4 x 4 x 2 m^3) to farm the fish. Under production trial conditions, the tilapia were raised in cages at varying stocking densities (800, 1 600, 2 400 and 3 200 per cage) with Mekong giant catfish (*Pangasianodon gigas*), the giant catfish from the Mekong River, being cultured in the ponds. Tilapia were fed with commercial floating pellets (28 percent crude protein), 3 times a day at 3 percent of biomass per day.

The survey revealed that the average number of cages operated by each farmer is 20, with a minimum of 4, and a maximum of up to 200 (Table 6). The size of the cages that are used varies from 13.5 m^3 up to 120 m^3, and stocking densities range between 3 and 100 fry/m^3. Under these production conditions, the amount of tilapia that could be produced varies from 9 to 83 kg/m^3. Although cage farmers use expensive commercially produced pellets, they still can make profit as their fish attain high market prices, i.e. 50 Baht/kg (range 35–62). The data showed that the price of feed accounts for approximately half of the production costs.

TABLE 6
Characteristics of cage based tilapia grow-out farms in Thailand

	Average	Minimum	Maximum
No. of cages/farmer	20	4	200
Cage size (m^3)	41	13.5	120
Stocking density (fry/m^2)	47	3	100
Yield (tonne/m^3)	39	9	83
Feeding frequency (time/day)	3	2	3
Amount of feed (kg/cage/time)	4	3	5
FCR	1.6	1.4	1.8
Feed price (Baht/kg)	23	18	31
Sale price of fish (Baht/kg)	50	35	62

Currency: Thai Baht 32.5 = US$1

Source: Field survey (2010).

3.3.3 Culture in tanks and raceways

A few hatcheries employ re-circulating tank technology for rearing fry but commercial grow-out using this method is not currently practiced in Thailand. However, tanks represent a suitable technology in areas where land and water are scarce. Research has shown that tilapia grows well at high densities in tanks; however this requires good water quality to be maintained. Water quality is maintained by aeration and frequent or continuous water exchange to remove metabolic wastes. Intensive tank culture offers several advantages over pond culture. The high stocking densities in tanks disrupts the breeding behaviour of the fish, and allows both males and females to be grown together to marketable size. In addition, tank culture enables the farmer to exert a relatively high degree of environmental control over the culture parameters (e.g. water temperature, DO, pH, waste), and these can be adjusted to maximize production.

Intensive tilapia culture in re-circulating or flow-through tanks/raceways is one of the preferred techniques for large-scale commercial production. Water re-circulating systems generally replace 1–10 percent of the volume of the system per day. The rearing tanks are aerated as in flow-through systems, and use low water exchange rates. These practices ensure high yield per unit area and/or unit volume of water. Important processes in these systems include the removal of solids and dissolved metabolites. Significant volumes of water are needed for this purpose. In water-limited areas, intensive tank and raceway culture requires water treatment and recirculation (Cole *et. al*., 1997). In tanks and raceways, tilapias are cultured under high density conditions. These systems are especially attractive in areas in which the effluent streams can be used for field crop irrigation as they provide a good source of fertilizers (Fitzsimmons, 1997).

In raceway systems, fingerlings (25–30 g) are stocked at 150–300 fish/m^3. The grow-out period for these fish is usually in the region of 120–150 days. Fish are fed formulated feeds at 3 percent of body mass per day at a feeding frequency of 3–4 times a day. Bi-weekly sampling is undertaken to establish growth rates, and the fish sizes are used to adjust the feeding rates. Fish are harvested when they reach 200–250 g. Stocking densities in raceway systems is in the region of 40–60 kg/m^3. Currently in Thailand, the high capital costs required for tank construction and the operational costs associated with using formulated feeds are prohibitive; under the prevailing economic conditions farmers using these systems were not able to make profits. Thus tilapia farming is currently primarily pond based, and uses cheap feeds. Should the economic fundamentals change, intensive tank culture may become profitable – particularly if

Thailand starts to export large volumes of high value product. In 2006, Thai tilapia exports were only ~5 000 tonnes (Belton *et al.*, 2009) and, in recent years, low cost production in China has precluded the development of a viable tilapia export sector in Thailand.

3.4 Feed production and management

Tilapia are capable of utilizing a wide variety of food sources, either as single sources or as components of compound feeds. Tilapia accept feed as dry meal, moist meal and pellets. Particle size is also an important consideration for tilapia culture as they generally prefer smaller feed particles than other cultured fish species.

In terms of commercial production, farmers use formulated pelleted aquafeeds and apply relatively low levels of fertilizer to stimulate the natural productivity in the culture waters. At high culture densities, natural feeds play an insignificant role in providing nutrition to the fish. In terms of feed management, the fish can either be fed to satiation or *ad libitum* or fed a restricted ration. Feeding *ad libitum* may result in higher growth rates but may not be the most economical way to culture the fish; as it is difficult to determine satiation levels in fish, feeding to satiation can lead to overfeeding, feed wastage, and poor water quality. Feeding restricted rations is therefore recommended. Calculating rations requires various factors to be taken into consideration, including body size, temperature and water quality. Most farmers do not adjust feed rations but feed near to satiation; however, weekly adjustments based on body size can be used as guidelines (Table 7). Grow-out fish are generally fed between 1 and 4 times a day with the amount of feed being reduced if the feeding response is poor. Demand feeders may be used.

TABLE 7

Feeding rates based on the fish weight and culture system

Weight of fish (g)	Feeding rate (% of body weight per day)	
	Intensive	Semi-intensive
0–15	15	10
15–60	18	5
60–100	5	3
100–200	3	2
200–300	2.25	1.5
300–500	2	1.4
>500	1.6	1.3

Source: Aquanutro (2002).

Red tilapia are raised using high quality commercial aquafeeds, normally in cages. The production is designed to supply local restaurants, superstores (e.g. TESCO, Big C) and the more affluent urban consumers. In contrast, Nile tilapia is mostly raised using manures and other recyclable wastes in earthen ponds at low cost, and with little attention to quality. Most Nile tilapia producers and consumers are located in rural areas and are relatively poor.

Tilapia are reared in tanks, cages or earthen ponds both in freshwater and in brackishwater up to 25 ppt salinity. Red tilapia are more tolerant of high salinities than the Nile tilapia, and some strains can even be raised in full strength seawater. Concomitant with some other species, tilapia has the ability to consume phytoplankton, and as a result, pelleted feeds are not necessary for growing tilapia at low densities in nutrient-enriched, 'greenwater systems'. These systems can produce marketable fish of

300–500 g within six months In addition to phytoplankton, tilapia can also consume zooplankton, detritus, aquatic plants and insects. Commercial pellets, waste foods, and most other food sources with the exception of meat, can be fed to the fish. Stocking densities, the size at stocking and culture methods are important considerations in terms of managing feed and feeding systems (Table 8). As stocking density increases, more investment is required in feed, and production costs will increase. In most parts of Thailand, farmers using supplementary feeding stock 18 000 fry of 2–3 cm (0.2 g), or 10 000 fingerlings of 9–10 cm (30 g) per ha in fertilized ponds. Higher stocking densities and investment in aeration are appropriate production strategies in areas where tilapia prices are high To make viable returns on investment on a per kilogram basis, fish prices must be at least double the cost of good quality commercial feeds. Red tilapia, for example, command a high market price (70–80 Baht/kg), and are raised at 2–3 fish/m^2 to 700 g using high quality commercial pellets. Typical harvest volumes using these parameters are in the region of 12–18 tonnes/ha.

TABLE 8
Feeding and other inputs suggested for tilapia culture in ponds in Thailand

Fertilization and feeding regime	Number of fish stocked/ha			
	2–3 cm	4–5 cm	6–7 cm	8–9 cm
Fertilization only	15 000	12 500	11 250	10 000
Fertilization only, higher density	20 000	16 500	15 000	14 000
Fertilization, supplemental cheap feed	21 250	17 800	16 250	15 300
Fertilization, supplemental cheap feed, higher density	28 750	23 750	21 250	20 000
Complete feed, no aeration, low density	16 000	13 400	12 000	11 250
Complete feed, aeration, high density	32 000	27 000	24 000	22 800

Source: Field survey (2010).

3.4.1 Natural foods

Greenwater systems provide natural feeds for the fish. The algae remove nitrogenous compounds and produces oxygen for the fish. The greener the pond, the more natural food there is available and, depending upon stocking densities, little or no supplemental feeding may be required. However, if a pond is too green, fish mortalities can result from insufficient dissolved oxygen levels, especially early in the morning when the algal biomass utilizes the dissolved oxygen in the water.

In order to create a plankton bloom, it is necessary to add nitrogen and phosphorous (N and P, respectively) – the two major limiting nutrients to plankton growth in water. The recommended application levels of these elements are 1–2 kg P/ha/day and 4 kg N/ha/day. The N and P can be derived from many sources, including chemical fertilizers, animal manures, 'ami ami' (monosodium glutamate factory waste), and composts. While the use of chemical fertilizers represents the most expensive option, in comparison with the other fertilizers, their use results in the best water quality. Fertilization is usually carried out every few days or on a weekly basis. Generally, the amount of fertilizer that is required is determined by the level of the existing algal bloom.

In general, there is an increase in fertilizer requirements throughout the growth period. Less fertilizer will be required where commercial feeds are applied, as they also contain N and P that can be utilized by the algae. Table 9 presents typical fertilizer inputs that are commonly applied in static semi-intensive ponds, and serves as a guideline. Farmers producing more fish use higher densities and supplementary feeds, and fertilize the ponds.

TABLE 9
Inputs used by the farmers for tilapia farming in ponds in Thailand

Type of input	Amount used (kg/ha/week)
NPK (16-20-0) chemical fertilizer	188
46-0-0 (urea) + 0-46-0 (phosphate)	56 + 69
Fresh chicken manure	1 875
Fresh chicken manure + 46-0-0 (urea)	1 100 + 25
Fresh pig manure	5 000
Cow/buffalo manure	6 250
'Ami ami'	12 500

NPK = nitrogen, phosphorus and potassium
Source: Bhujel (2012).

Chemical fertilizers are applied weekly (or more frequently if required) by dissolving them in water, and broadcasting the solution over the surface of the pond. There are no strict guidelines for the application of animal manures. Most farmers either broadcast the materials over the pond water, or apply the manure to a few selected spots located around the edge of the pond. Frequent manuring in small amounts is advisable, and usually one application per week is sufficient.

3.4.2 Feeds in pond culture

There is an important relationship between feeding and stocking density. Production costs increase with increasing stocking density, and feed is only required once pond biomasses rise to 4 000–5 000 kg/ha. However, feed can be used to increase growth rates and so reduce culture periods. For example, while red tilapia will attain a size of 700 g within 4 months in ponds when fed a complete formulated commercial feed, the same fish could be raised to 700 g in 6 months using a lower ration and/or a cheaper formulation, It is therefore important to determine whether the fast grow-out period justify the increased feed costs necessary. When considering the use of feeds and their effect on culture periods and production prices, other factors such as land, water and pond excavation costs also need to be considered. Where the cost of land rental or purchase is expensive, higher density feed-lot type systems become more economic.

As the prices of tilapia grown in ponds are very low in Thailand, it has not been economically worthwhile to feed expensive commercially formulated feeds to date; the prices of good quality commercially formulated feeds are almost similar to the sale price of the fish. As a result, pond farmers need to identify alternative, cost effective, cheap feed inputs. Currently these include:

- waste food from restaurants, hospitals and schools.
- rice bran, broken rice and oil cakes.
- bread, wafers, yeast and other edible factory wastes.
- waste animal feeds.

In contrast, the price of tilapia raised in cages are approximately twice those of pond-reared fish, and the use of good quality commercially produced feeds are cost effective. The advantages of using high quality floating feeds are increased ingestion rates, decreased feed losses and improved digestion, resulting in faster growth, and a reduction in effluent streams. Farm-made sinking pellets are generally cheaper to produce than commercially produced floating aquafeeds, and are prepared from a multitude of feedstuffs using simple grinders and mixers. However, as these feeds sink and the farmers are unable to monitor feed consumption, feed wastage tends to be

higher than when floating feeds are used. Sinking pellets are not used for cage culture as they tend to be lost through the bottom of the nets; thus cage farmers tend to use more expensive floating commercial pellets. However many indicate that they have issues in terms of the quality and price of these feeds. As the extruders that are required to produce floating pellets are expensive, almost all farmers produce sinking pellets. The floating commercial pellets that are available on the market are fairly standard, and primarily differ in terms of crude protein level and pellet size. Prices increase with an increasing level of protein. Protein levels under 20 percent are not recommended for tilapia, as poor palatability tends to be an issue. During the survey, it was established that most farmers use feeds containing around 25 percent crude protein during the final grow-out period; they reported that this protein level/cost was the most cost-effective to use.

3.4.3 Feeds in cages

Tilapia cage culture is widespread in rivers, canals and reservoirs in Thailand. Large scale cage culture has in cases been shown to be problematic as it can obstruct boat traffic and cause substantial pollution to natural waterways. Many farmers are attracted to tilapia cage culture as it negates the need to buy or rent land, and capital investments are relatively low. However, the disadvantages of using these systems are that running costs are higher than pond based systems, and large amounts of commercial feeds have to be used. Production risks are also a factor and are deemed to be relatively high – water quality and disease cannot be controlled easily, and there is always the possibility of fish escaping from the cages. Tilapia cage culture is only economically profitable when the prices for the fish are high, and it is for this reason that the more valuable red tilapia are mainly raised in cages in Thailand. Floating pellets are essential in cages, and most farmers feed *ad libitum* and 2–3 times daily. A range of commercial feeds is illustrated in Figure 7. A band of fine netting material is installed inside the cage at the water surface to avoid floating pellets from moving beyond the cages. The crude protein levels in these feeds range between 25 and 36 percent and, while food conversion ratios are generally lower for the high protein feeds, they are more expensive.

FIGURE 7
These commercial feeds, with differing levels of crude protein, are especially formulated for tilapia farming in Thailand

COURTESY OF FAO/R.C. BHUJEL.

3.5 Feeding methods in commercial farming

Tilapia can either be fed by hand or by automatic or demand feeders. Hinshaw (1999) suggested that irrespective of whether feeding was by machine or by hand, feed should be distributed throughout the pond to allow all the fish access to the feed, and that feed should not be allowed to accumulate on the bottom of the ponds. Nile tilapia feed throughout the water column, and thus both floating and sinking feeds are suitable for this species. Webster and Lim (2002) suggested that

demand feeders may provide the best feeding method in cages as they supply feed at a low labour cost. In this regard, Jaruwan (2008) demonstrated that mobile blower feeders used more feed than the fixed station feeders; thus production costs using blower systems, although not great, were higher than those when other feeding systems were used. The same study found that there was no significant difference in terms of fish production between using fixed station feeders and mobile blower feeders; however, it was recommended that fixed station feeders instead of mobile blower feeders should be used as the former resulted in slightly higher profits and lower feed and labour costs.

Water quality can affect fish growth. Feeding should be reduced or ceased when water quality is poor. Dissolved oxygen levels higher than 5.0 ppm are considered optimum for growth. When DO declines below this optimum, the feeding rate should be reduced, and ceased once DO falls below 3.0 ppm. Ammonia concentrations are related to feeding practices, and are dependent on temperature, feeding rates, the size of fish and the feed quality (Riche and Garling, 2003). Appetite is also temperature related, and the fish usually stop feeding when temperatures fall to 15 °C or below. In addition, Tongdee (1995) demonstrated that when the pH is 5 or below, there is a sharp decline in feed consumption.

3.5.1 Hand feeding

In Thailand, feeding is primarily undertaken by hand using broadcast methods from the pond dykes or from boats. Some of the larger farms use mechanical feeders (blowers/demand feeders). As these machines are expensive, most of the smaller farmers use hand feeding. However, in those areas where labour is difficult to find, automatic/demand feeders are used. Automatic/demand feeding requires lower labour inputs but normally results in increased feed wastage. In addition, feeding manually provides an opportunity to observe the fish and to monitor their condition, and also provides an opportunity for corrective actions. However, with an increase in farm size and intensification, mechanical feeding is rapidly becoming indispensable. Feeding methods are designed to suit the culture systems, and take into consideration pond sizes, species, budget, and the type of feed used.

3.5.2 Fixed station feeder

There are a number of types of fixed station feeders. Demand feeders are cost effective, and use minimal labour and respond effectively to the appetites of the fish. However they have disadvantages in that they can only deliver feed to a localized area, and cannot be used with fish smaller than 20 g. In contrast, compressed air feeders distribute feed over a wider area, and can service up to 5 000 fish per feeder. Some of the large commercial tilapia farms (e.g. Manit Farm) use sophisticated pneumatic fixed station automatic feeders. These feeders disperse feed using compressed air. Pneumatic feeders are specifically designed for feeding in large ponds or raceways. These systems have the advantage of distributing large amounts of feed (up to 120 kg dry feed) through multiple distribution pipes. The disadvantages of these feeders are that they require electrical power and are relatively expensive to operate.

3.5.3 Mobile blower feeders

Mobile feeders can be used to distribute feed to ponds that have suitable road access. These feeders are manually operated, and are usually mounted on trucks, push carts, or towed by tractors. The feed is distributed at a velocity of 0.53 m/second to distance of 4 and 10 m into the pond. It has been observed that the use of fixed station feeders can result in poor water quality in the vicinity of the feeder and, due to competition for feed around the feeders, variable fish sizes at harvest. These problems can be resolved by using mobile feeders that distribute the feed evenly throughout the pond.

3.6 Feed industry, transportation and storage

In general feed companies deliver the feed to the famers. The farmers can purchase their feed from a number of feed companies; the main companies offering tilapia feeds in Thailand are the CP Company, Thai Luxe, AquaStar, and Cargill Inc. These companies produce feed types according to market requirements, and they generally have branch factories across the country with distributors working in almost every district, especially in the central region.

Feed ingredients are also delivered by the feed traders and distributors. When purchase volumes are low, the farmers are usually responsible for transporting the feed to their farms. Once the feed or feed ingredients are delivered to the farms they are either stored in a feed storage area in a house or near the ponds. Prior to use, the farmers often store their feed for a week or so in large buckets at the pond or cage sites (Figures 8 and 9). Although these buckets are covered by lids, excessive heat can in some cases negatively affect the nutrient composition of the feeds.

4. SUMMARY AND RECOMMENDATIONS

4.1 The current status of the pond and cage culture sectors

In the past tilapia culture in Thailand has been viewed as a subsistence activity; however, in recent years it is increasingly becoming seen as a viable commercial proposition. Currently, the domestic market for tilapia has stabilized but export markets still need to be developed. Current production is primarily based on pond and cage culture systems; a comparison between these production systems is presented in Table 10. In terms of comparing the various production technologies, cage culture has an advantage over pond farming in that the fish that are produced are larger, are of a better quality with improved organoleptic properties, and are suitable for export. However, cage culture usually requires the use of relatively expensive manufactured aquafeeds that are in the region of twice the cost of those feeds used in pond culture (pond culture: 12 Baht (US$0.37)/kg feed; cage culture: 23 Baht (US$0.71)/kg feed; Table 10).

FIGURE 8
Feed stored in plastic bucket on-site for tilapia fry nursing

COURTESY OF FAO/R.C. BHUJEL.

FIGURE 9
Buckets containing feed on-site (left) and feeding operations in cages (right)

COURTESY OF FAO/R.C. BHUJEL.

TABLE 10
Summary of findings of survey on tilapia farming in Thailand

Parameter	Pond culture	Cage culture
Average stocking density (fry/m^2)	2.4	47
Feeding frequency (time/day)	2	3
Application of chicken manure (kg/ha)	866	–
Amount of feed (kg/ha/day)	128	4 (per cage)
Average yield (tonnes/ha)	6.1	39 kg/m^3 cage
Fish growth (g/day/fish)	1–1.5	2–3
Final size of fish (g)	200–500	500–1 000
FCR	0.6	1.4–1.8
Average feed price (Baht/kg)	12	23
Average sale price of fish (Baht/kg)	32	50

Currency exchange rate: Thai Baht 32.5 = US$1.0.

Source: Field survey (2010).

Cage farmers also have to feed more often than pond farmers (3 times a day or more in cages), with feeding rates for the cage cultured fish typically being between 3 or 4 times higher than fish grown in ponds. The higher feeding rates and frequencies used in cages result in higher daily growth rates (2–3 g/day), but lower food conversion (FCR: 1.4–1.8:1). In general, Nile tilapia are still considered low-priced fish in Thailand but production prices remain higher than fish produced in other countries such as China. In this regard, Thailand is trying to compete on production costs, and to explore potential export markets for Thai tilapia. The extensive adoption of high quality feeds for use in pond culture systems will only be possible if Thai pond farmers can develop sufficient economies of scale to reduce production costs in line with other exporting countries. As cage culture systems require floating pellets and the extruders that are needed to produce pellets are normally expensive, it is a real challenge for the farmers to prepare appropriate farm-made feeds. Importantly, the use of low quality feeds and feed ingredients negatively impacts the quality of the fish that are produced. A wide range of commercial pellets are available in the country. However, the careful selection of cost effective feed is an important consideration that farmers do not always address

appropriately. Fish farmers need training to improve their feed management practices, formulations, preparation, and storage practices. Appropriate record keeping to determine those feeds and management practices that result in improved production is also an issue that need to be addressed. In this regard, the production and distribution of a manual outlining these practices should be considered.

A major contributory factor to the recent growth of the tilapia industry in the country is the availability of quality sex-reversed tilapia fry. A single hatchery can produce up to 20–30 millions of fry per month, generating considerable revenue streams. The success of the technology and the development of various hatchery business models has attracted both local and foreign private sector investors, and created significant employment opportunities. At present, one large scale hatchery in central Thailand employs in the region of 200 local staff/workers, and several NGOs/Missionaries/Foundations are using tilapia culture as a tool to promote rural development. The development of suitable broodstock farm-made feeds or the purchase of suitable commercial feeds at reasonable prices remains an issue for the hatchery operators. Similarly, the use of fishmeal, MT hormone and alcohol for sex-reversal are the major cost concerns. To reduce the reliance on expensive MT and alcohol, research is underway to find alternatives to MT, e.g. papaya seed, herbal plants and/or other sources of natural hormone. Cheap mono-sexing methods would be beneficial to the hatchery owners, and any protocols avoiding the use of these chemicals would allay the environmental fears that are sometimes attributed to their use.

The major problems that are currently encountered by tilapia farmers in Thailand include the following:

- The high price of good quality commercial pellets is problematic and makes cost effective production difficult.
- Farmers often lack the necessary information needed to formulate well balanced farm-made feeds; there is lack of farm-made feed formulations that provide examples for the farmers.
- Poor organoleptic properties or 'off-flavours' are frequently reported in fish that are produced in greenwater systems; this reduces their value and marketability.
- There are variations in the sizes of fish harvested from pond culture systems.
- The research community places insufficient emphasis on developing on-farm trials involving farmers.
- There are no dedicated broodstock feeds available, and farmers have to rely on commercial grow-out feeds.
- There are no commercially available nursery feeds.
- Only expensive fishmeal are used during the sex-reversal process, and as a result, the price for fry is high; currently, there is no viable alternative to fishmeal.
- Feed quality monitoring systems are inadequate, especially in terms of farm-made feeds.
- Tilapia farms, feed manufacturers and distributors need to be certified.

4.2 Future scope and needs

High quality commercially produced aquafeeds are expensive and many farmers try to limit their use as they increase production costs. The development of good quality farm-made aquafeeds could potentially increase productivity, improve profits and promote sectoral growth. Currently, farm-made aquafeeds are uncommon in Thailand, especially so for tilapia. Most farmers use formulated feeds as opposed to preparing their own feeds. Usually, pond farmers either buy cheap commercially produced pellets, or use cheap by-products as feed. To date, no research has been carried out to compare the performance of these dietary formulations in terms of growth, survival, food safety, or the economic implications of using these feeds and feeding practices.

While some farmers actively investigate potential alternatives to purchasing pelleted feeds, they typically use by-products that are high in carbohydrates but low in protein. As protein promotes growth in fish, the addition of at least one of the locally available protein sources, e.g. soybean meal, chicken feather meal, etc., would greatly enhance the quality of the feeds they use. This could be achieved without adding substantial cost to the formulations. Providing feed formulation, preparation, storage and feed management training to the farmers could significantly improve the efficacy of formulations and farm feed management practices. While a significant amount of research has been undertaken to establish the nutritional requirements of the species group, most of the results of this research has not been communicated to the farmers. Simple informative training manuals and the conduct of participatory feeding trials in farmers' ponds could improve their understanding, and promote the use of effective farm-made feeds.

In general, the animal wastes and agricultural by-products that are used in feed formulations are of low nutritive value, and are poorly digested by the fish. Their use can result in negative environmental impacts as the undigested nutrients accumulate in the environment. In order to limit the negative environmental impacts accruing to the use of these feed ingredients, it would be appropriate to develop regulations. For example, minimum digestibility coefficients of 60 percent could be used to promote the use of digestible feedstuffs. Pond water quality and improvements in water quality management are also issues that need to be addressed. Poor pond water quality can cause poor flesh quality and taste, resulting in low product values. While this is not an issue among domestic consumers, it remains an important consideration when penetrating export markets.

While tilapia farming has become increasingly popular in Thailand over the past decade, there remain significant constraints to penetrating export markets and competing in the global markets with low cost producers such as China and certain countries in South and Central America. Attempts have been made to reduce production costs and explore niche markets in the Gulf countries and Europe. In addition to promoting more cost effective production technologies, there is also a need to improve traceability and product safety. In this regard, maintaining quality standards and food safety has been the focus of a national policy for the shrimp industry. The tilapia industry could benefit from the application of those practices that have been developed for the shrimp sector.

The following recommendations have been developed to improve tilapia farming in Thailand:

- The promotion of farm-made feeds using locally available ingredients needs to be prioritised. Farmers and researchers need to collaborate, conduct trials and disseminate the proven formulations to the industry.
- Farmers require training to improve their feed storage and management practices.
- Research is required to resolve the poor flesh quality that is associated with growing tilapia in pond culture systems.
- The negative environmental issues associated with nutrient enrichment through the use of poorly formulated feeds and their application needs to be resolved. Similarly, the use of methyl-testosterone to produce mono-sex populations should be controlled.
- The tilapia dialogue facilitated by the World Wide Fund for Nature (WWF) has developed guidelines for responsible tilapia culture. These guidelines should be applied in Thailand. Alternatively, Good Aquaculture Practices (GAP) or similar certification programmes should be made mandatory for those wishing to export tilapia.
- A manual for producing good quality tilapia using farm-made feeds should be published and distributed to the farmers.

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ANNEX 1

On-farm feeds and feed ingredients used in tilapia farming in Thailand and their prices

	Feeds/feed ingredients	Price (*Baht/kg)	Price (US$/kg)	Remarks
1	Urea	22	0.68	
2	TSP (triple super phosphate)	23	0.71	
3	Lime (CaO)	5.6	0.17	
4	Chicken manure	0.4–1.6	0.01–0.05	
5	'Ami Ami' **	1.0	0.03	Small quantity = 10 Baht/kg
6	Maize meal	6–6.5	0.18–0.20	
7	Left over/wastes of chicken feed	4.0	0.12	Cheapest feed
8	Rice bran (fine)	7.50	0.23	
9	Cassava flour	35	1.08	
10	Soybean meal	40	1.23	
11	Fishmeal (local)	35	1.08	
12	Fishmeal (imported)	38	1.17	
13	Catfish pellet (25% CP)	17.25	0.54	
14	Catfish pellet (30% CP)	19	0.58	
15	Catfish pellet (35% CP)	24.5	0.75	
16	Catfish pellet (40% CP)	49	1.51	
17	Shrimp starter (40% CP)	42	1.29	
18	Vitamin C	150	4.62	
19	Methyl testosterone (per g)	749	23.05	
20	Alcohol (ethyl alcohol 95%)	78	2.40	
21	Tilapia feed (floating, 30% CP)	23	0.71	
22	Food wastes from restaurant	0.71	0.02	
23	Salt	3.25	0.10	
24	Mineral mix	45	1.38	
25	Vitamin mix	240	7.38	

* US$1 = Thai Baht 32.5.

** Wastes from monosodium glutamate factory; CP = crude protein.

ANNEX 2

Prices and composition of major feed ingredients in Thailand

Feed ingredients	Approx. price (US$/kg)*	Moisture (%)	CP (%)	EE (%)	CF (%)	Ash (%)	Ca (%)	P (%)
Broken rice	0.3	12.57	7.02	1.12	0.43	0.75	0.01	0.16
Cassava root	0.2	10.34	2.14	0.62	2.05	2.69	0.09	0.07
Maize bran	0.3	12.50	7.58	3.62	5.63	2.21	0.04	0.26
Cassava leaves	0.1	12.32	27.39	7.17	10.90	7.02	1.20	0.30
Chicken viscera meal	0.6	8.00	56.50	22.30	2.70	4.11	3.60	1.54
Maize grain	0.3	12.56	8.71	4.13	1.71	1.29	0.01	0.26
Coconut oil meal	0.3	10.00	21.00	6.00	12.00	7.00	0.20	0.20
Fishmeal (60% CP)	1.0	8.00	55.20	8.01	1.00	26.00	7.70	3.80
Kapok oil meal	0.2	10.24	32.58	2.38	21.62	7.22	0.40	1.03
Duckweed (Lemna minor)	0.1	9.50	29.00	4.21	7.26	20.30	0.02	0.63
Leucaena leaves	0.2	10.05	23.54	7.70	7.68	9.71	2.52	0.17
Leucaena seed	0.3	10.30	27.80	7.06	10.25	4.04	0.39	0.05
Parboiled rice bran	0.2	9.07	13.32	27.25	9.72	9.44	0.14	2.08
Sago stem	0.3	10.14	1.23	1.80	13.32	8.88	0.84	0.02
Sesbania leaves	0.1	7.85	29.56	4.85	7.47	10.55	2.30	0.30
Tofu waste	0.4	90.53	2.60	0.82	1.83	0.39	0.06	0.02
Water hyacinth	0.1	92.73	1.65	0.26	1.27	1.37	0.13	0.06
Winged bean	0.5	9.31	6.79	0.23	36.95	8.89	0.44	0.09
Peanut oil meal	0.4	7.59	49.91	5.79	3.95	8.18	0.14	0.65
Rice bean (extract)	0.2	11.08	15.73	2.35	10.26	12.87	0.17	2.26
Sesame meal (black)	0.3	7.46	33.84	16.42	5.57	12.23	2.52	1.22
Shrimp head meal	0.6	10.26	30.59	3.77	10.55	n.a.	8.16	1.60
Soybean meal	0.5	9.50	44.30	5.30	5.70	6.00	0.83	0.66
Sunflower seed meal	0.4	7.57	21.64	7.61	29.05	6.75	0.63	0.67
Wheat flour	0.5	13.10	15.40	1.90	0.50	0.90	0.06	0.13

*Prices have been updated based on the current situation.

Source: Proximate composition from Somsueb (1993) and Thongrod (2007).

On-farm feed management practices for Nile tilapia *(Oreochromis niloticus)* in Ghana

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ABSTRACT

This paper records the results of a study investigating on-farm feed management practices for the Nile tilapia (*Oreochromis niloticus*) aquaculture in Ghana. On-farm feed management practices were assessed at some randomly selected locations, examining various aspects of feed use in some earthen fishpond and fish cage farms. Earthen fishpond farms are widely scattered throughout the country whilst fish cage farms are concentrated on the Volta Lake. Fish production from aquaculture was 5 594 tonnes in 2008, which is only about 1.5 percent of domestic fish production. Fish farming is thus an emerging industry in Ghana. Nile tilapia accounts for over eighty percent of aquaculture production. Three types of feeds are in use; farm-made, locally produced and imported commercial feeds. Fish feed production and use have not been managed in earthen fish pond farms in a way that ensures maximum returns for farmers. Fish cage farmers were found to depend mostly on imported commercial feeds. Farm-made feeds for Nile tilapia were coarse, crumbly, powdery and sinking. Imported feeds were in pellet form, smooth and mostly floating. Areas into which research should be directed and the need for regulations to ensure the certification of fish feeds (both imported and locally produced) are suggested. The importance of proper storage of feeds was highlighted. Major knowledge gaps exist amongst the earthen fishpond farmers in feed formulation, preparation, use and management.

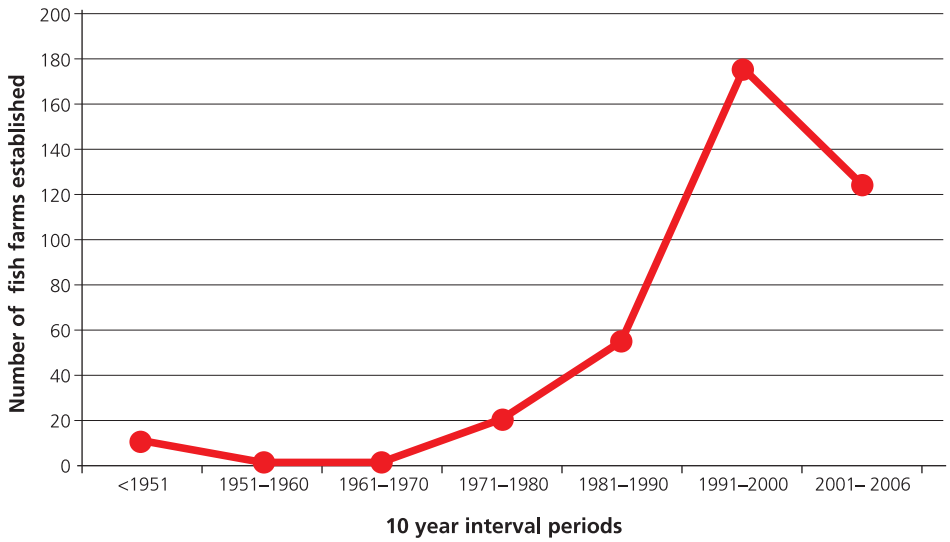
1. BACKGROUND

1.1 Introduction

The global farmed production of tilapia in 2008 was 2.8 million tonnes, valued at around US$4.0 billion (FAO, 2012). The most commonly cultured species in Africa is the Nile tilapia (*Oreochromis niloticus*) (Balarin, 1988). Aquaculture has been practiced in Ghana since 1958 (Abban *et al.,* 2009) when it was initiated as a component of a culture-based fisheries development programme. The programme involved the production of tilapia fingerlings in earthen fishponds to stock small reservoirs constructed in villages. During this period the pond farming of Nile tilapia (*Oreochromis niloticus*) was initiated in northern Ghana. In the initial years production remained low; however it subsequently spread to the rest of the country (Prein and Ofori, 1996). The growth of the sector (number of ponds constructed for this purpose) was greatest during 1980–2000 (Figure 1),

a period when it was promoted by the National Fisheries Department. During that period, several agricultural by-products (including guinea corn and maize chaff) were used as aquafeeds. At the same time organic manures, such as livestock droppings, were applied to stimulate natural production in the ponds. The sector has subsequently diversified, and became based on pond, pen, cage, and hatchery technologies (Prein and Ofori, 1996).

FIGURE 1
The number of aquaculture ponds in Ghana



Note: The increase in the number of fishponds constructed in Ghana can be considered as an index of the growth of the tilapia farming sector in Ghana.
Source: Asmah (2008).

Small-scale earthen fishponds are distributed throughout the country and account for 98 percent of the fish farms (Asmah, 2008). To date, irrigation sites have been favoured for development, and farming operations are currently concentrated in those areas. Alternatively, farms comprise small aggregations of earthen ponds that have been constructed by individual farmers. Fish pens and cages are primarily located in the Volta Lake (Asmah, 2008). This author estimated that over 96 percent of all the fish farms are subsistence farms, about three percent are small-scale commercial farms, and less than one percent are medium to large scale commercial farms.

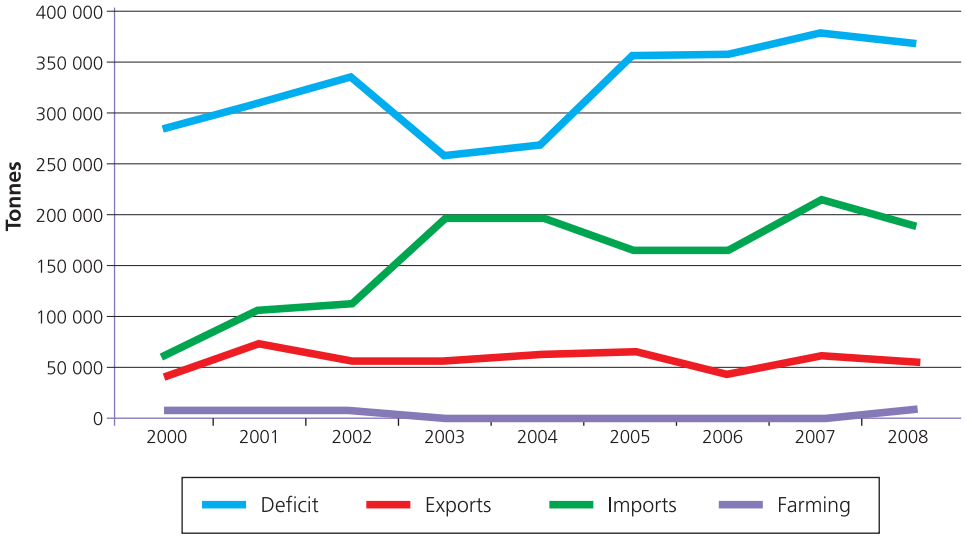
1.2 National farmed fish production

The largest commercial fish farms are cage farms (DoF, 2009). Sixty-eight percent of commercial fish production is derived from cage farms, twelve percent from earthen ponds, nineteen percent from small reservoirs (culture-based) and one percent from fish pens. In 2009, two commercial fish cage farms produced approximately 1 000 and 3 500 tonnes of tilapia respectively (DoF, 2009). Nile tilapia accounts for over 80 percent of national commercial fish farming production. The rest primarily comprises the African sharptooth catfish (*Clarias gariepinus*) and other species, including the African arowana (*Heterotis niloticus)* and the catfish *Heterobranchus* spp. (FAO, 2010).

According to FAO (2012) domestic production (from both capture fisheries and aquaculture) in Ghana was 365 425 tonnes in 2008. Of this, aquaculture accounted for about 1.5 percent (5 594 tonnes). At that time, the Directorate of Fisheries (DoF, 2008) estimated national fish requirements to be 931 198 tonnes and stated that total fish supply in 2008 was 566 513 tonnes (including imports) and there was a deficit of 364 685 tonnes, equating to 39 percent of the national fish requirement. Fisheries

contribute three percent to the total gross domestic product (GDP) of Ghana, and account for five percent of agricultural GDP. The national supply of fish is primarily from marine capture fisheries and the freshwater fishery in Lake Volta; these account for approximately 99 percent of fish production. To date, the contribution of aquaculture to total GDP has not been determined; however, it is evident that it is extremely small when compared to fisheries. In addition, fish are imported to make up for part of the shortfall in the national fish supplies. Despite the shortfall, some fish is still exported (Figure 2). Over the past decade, production from capture fisheries has not increased appreciably; however, the deficit in national fish production has shown a significant increase. The Ministry of Food and Agriculture has developed a policy calling for 60 percent of the national animal protein supply to be sourced from fish (MoFA, 2010).

FIGURE 2
National deficit in fish supply (tonnes) compared with exports, imports and production through aquaculture (2000–2008)



Source: DoF (2008).

1.3 Sector constraints and the potential to develop fishmeal replacement diets

Several challenges beset the industry. These challenges include land acquisition, seed and feed production and supply, credit availability and technology transfer (Abban *et al.*, 2006). Efforts to improve the growth rates of Nile tilapia, improvements to broodstock and seed production, and aquafeed and cage culture trials are in progress at the Water Research Institute of Ghana. An on-going study is aimed at developing models for allocating water space for cage culture on Lake Volta. Fish farming has been adopted by the DoF as one a means of increasing fish production and offsetting the deficit in supply (DoF, 2008). As a result, tilapia culture has gained prominence in Ghana. In 2008, 5 100 tonnes of Nile tilapia was produced, equating to 91 percent of total national aquaculture production recorded by FAO (2012). Feed generally accounts for between 30–60 percent of production costs (De Silva and Anderson, 1995), and in the past the unavailability of aquafeeds has limited production. Fishmeal or animal protein supplements are the main source of protein used in aquafeed formulations (Tacon, Metian & Hasan, 2009). A baseline survey of fish farmers in Ghana in 2003–2004 showed that a very wide range of materials were used, including agricultural by-products such as maize bran and wheat bran (Table 1) that are generally poor quality ingredients. Improving the nutrient availability in some of the available feed ingredients requires further processing (De Silva and Anderson, 1995).

TABLE 1

Fish feed inputs used by fish farmers in rural Ghana

Feed ingredients	Number of farmers per district				
	Upper Denkyira	Wassa West	Sefwi	Ashanti	Total
Animal origin					
Anchovy				2	**2**
Fresh blood/blood meal	1			3	**4**
Chicken offal				3	**3**
Fishmeal		1		2	**3**
Fish rejects			2		**2**
Intestines (unspecified)				1	**1**
Maggots				1	**1**
Poultry offal				2	**2**
Termites	1		4		**5**
Plant origin					
Bean flour			3		**3**
Brewery waste				2	**2**
Cabbage leaves		1			**1**
Cassava			5	4	**9**
Cassava leaves			1	1	**2**
Cassava - boiled				1	**1**
Cassava - cooked			3	1	**4**
Chaff*			1		**1**
Coconut chaff		1			**1**
Cocoyam leaves		1	5	2	**8**
Corn chaff/bran			13	1	**14**
Corn flour/meal		1	3		**4**
Food crops (unspecified)			1		**1**
Fruit (unspecified)			2	1	**3**
Gari fruit			1		**1**
Groundnut husks/peels	3	5	2	36	**46**
Kenkey**				1	**1**
Leaves (unspecified)		1	20	1	**22**
Maize				1	**1**
Maize bran	6	4	6	11	**27**
Maize chaff			1		**1**
Maize flour			1		**1**
Maize grits				2	**2**
Milling wastes (unspecified)		1			**1**
Palm fruit			2		**2**
Palm kernel oil cake	1				**1**
Pawpaw leaves			4		**4**
Pawpaw fruit	1		2	2	**5**
Pito mash		3		1	**4**
Rice bran	12	1	44	23	**80**
Vegetables (unspecified)	1			1	**2**
Wheat bran		14	3	5	**22**
Miscellaneous					
Commercial feed		1			**1**
Farm waste		4			**4**
Feed – unspecified		13			**13**
Kitchen waste	5	7	3	6	**21**
Local house feed (unspecified)			2		**2**
Poultry feed				4	**4**
Total	**31**	**59**	**135**	**121**	**346**

Source: FAO (2005).

Notes: *Dry, scaly protective casings of the seeds of cereal grain, or similar fine, dry, scaly plant material, such as the scaly parts of flowers, or finely chopped straw; **Fermented maize meal traditionally prepared by boiling balls of mixed portions of fermented cooked maize meal and raw maize dough.

The high cost of fishmeal has prompted research into developing cost-effective fishmeal replacements as protein sources. In Ghana, the cost of imported fish feeds with a protein content of thirty percent is above US$1.0/kg[1]. A feed development programme undertaken by the Animal Research Institute (ARI) of the Council for Scientific and Industrial Research (CSIR) established the availability, distribution, and seasonality of various agro-industrial by-products (Nelson and Wallace, 1998). Agro-industrial by-products such as guinea corn chaff, groundnut husk and cake are available in the northern parts of the country, and maize chaff is available throughout the country. Tilapia production trials to test the efficacy of using agro-industrial by-products in feed formulations have been undertaken for a number of species (Attipoe, Nelson and Abban, 1998; Ofori and Asamoah, 1996). Ofori (1988) demonstrated that rice bran could be used as a single feed input for Nile perch (*Lates niloticus*) culture, and obtained a yield of 1 427 kg/ha/year. Other trials testing the potential to use plant protein sources in dietary formulations for the African sharptooth catfish (*Clarias gariepinus*) are ongoing. Despite the presence of an anti-nutritional factor – mimosine (Francis, Makkar and Becker, 2001), leucaena leaves (*Leucaena leucocephala*) have also shown potential as a fishmeal replacement (Amisah, Oteng and Ofori, 2009).

1.4 Common feedstuffs and manure

The most common feedstuffs used in rural Ghana include rice, maize and wheat bran, various leaves, vegetables (primarily cassava leaf), and a variety of other foodstuffs (FAO, 2005). The leaves that are available include cocoyam and cabbage leaves, while the fruits include pawpaw and avocado pears. These materials are used as single feed ingredients (Table 1). With respect to organic manures, cow dung, grass-cuttings and sheep, poultry, goat and swine manure are applied (FAO, 2005).

To date, integrated agriculture/aquaculture systems have not been developed in the country, and aquaculture is undertaken as a stand-alone activity, with few linkages to other farming enterprises (Prein and Ofori, 1996). However, FAO (2005) reported that the use of agro-industrial by-products, plant materials and animal wastes in aquaculture is extensive (Table 2). Despite this, pond production based on these materials is problematic as supplies are often intermittent; sufficient quantities of these materials are rarely available throughout the year (Ofori, 1988). In this regard, it is important to determine the on-farm management strategies that are used by farmers to resolve these supply issues.

TABLE 2
Fertilizer inputs used by fish farmers in rural Ghana

Type of fertilizers	Number of farmers per district				
	Upper Denkyira	Wassa West	Sefwi	Ashanti	Total
Inorganic fertilizers					
Inorganic fertilizer (unspecified)		2			**2**
Nitrogen, phosphorus and potassium (NPK)			2	1	**3**
Organic manure					
Cow dung			2	4	**6**
Goat manure			10		**10**
Grasscutter manure				1	**1**
Organic manure (unspecified)	9	39	1		**49**
Poultry manure			25	35	**60**
Sheep manure			12	3	**15**
Swine manure			4	6	**10**
Unspecified				2	**2**
Totals	**9**	**41**	**56**	**52**	**158**

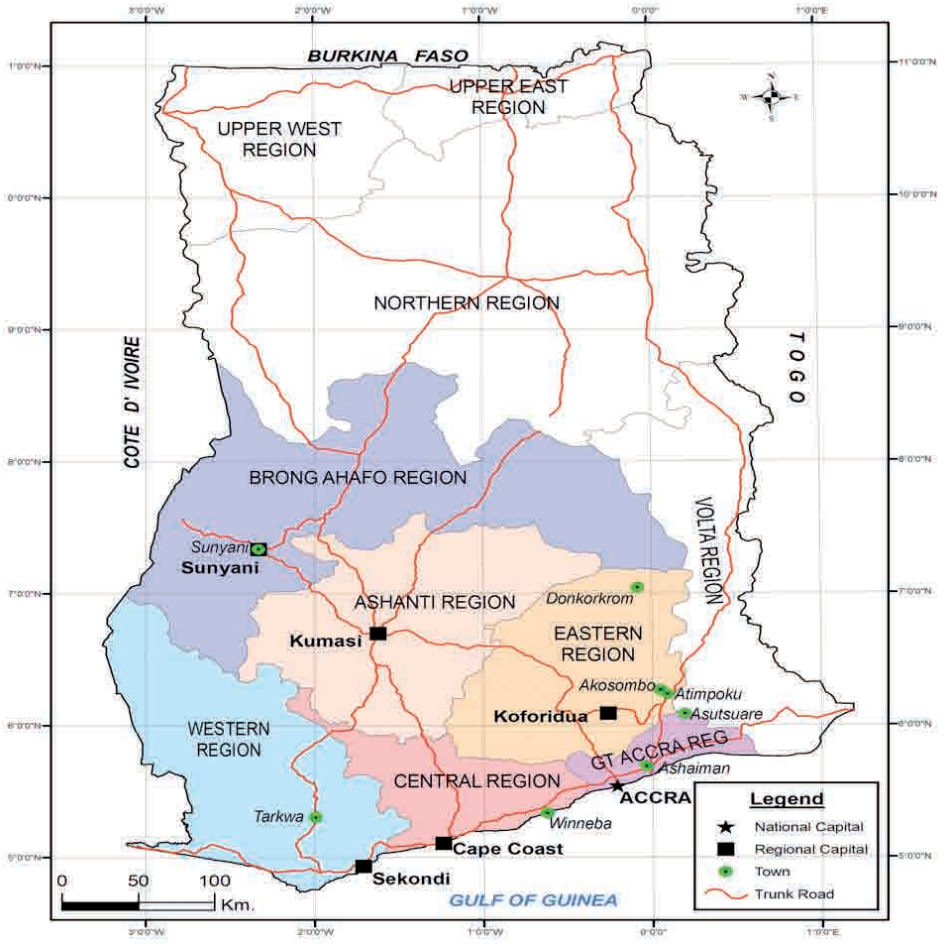
Source: FAO (2005).

[1] See Table 8 of this document.

2. METHODOLOGY

A review of current feed use and feed manufacturing practices for *O. niloticus* production was conducted at randomly selected locations in eastern, central and western Ghana (Figure 3). A total of four cage farms were surveyed in the eastern region of Akosombo (Lee's farm, Sang-you), South Senchi Solidarity (Atimpoku near Akosombo) and the Dim fish farmers group, not far from Donkorkrom in Afram Plains district. A total of fourteen pond farmers were surveyed. A description of the pond facilities and the respective levels of production is provided in Table 3. The fish cage farms comprise small production units. No large scale commercial fish cage farms were included in the analysis as they were unwilling to participate in the survey. The locations of the pond farms that were selected in the survey were Tarkwa, Terebe, Abosso, Achampong Krom, (all near Tarkwa) Tano-Odumase near Kumasi, Asutuare, Sunyani, Ashaiman and Winneba.

FIGURE 3
Map of Ghana showing the location of farms selected for the study



COURTESY OF H.K. HARRISON, WATER RESEARCH INSTITUTE, (CSIR), ACCRA

TABLE 3

Fish farm location, facilities and estimated production (2009)

Name of farm	Location	Type of culture system	Rearing facilities	Estimated production
Ashaiman	Ashaiman	Earthen ponds and concrete tanks	5 earthen ponds (12 m x 13 m each) and 12 concrete tanks (10 m x 5 m each). Tilapia fingerling production farm	1 140 000 fingerlings of tilapia produced
Achampong	Achampongkrom (Tarkwa)	Earthen pond	1 pond (0.05 ha)	0.075 tonnes
Dotsu	Adieyie (Tarkwa)	Earthen pond	1 pond (0.05 ha)	0.06 tonnes
Ansah	Winneba	Earthen pond and concrete tanks (new farm)	3 ponds (9.2 m x 10 m each) and 6 concrete tanks (5 m x 10 m)	20 000 fingerlings
Akrofi	Abosso (Tarkwa)	Earthen pond	3 ponds (0.1 ha each) and 6 small concrete tanks for fingerling production	0.25 tonnes
Vikwam	Abosoo (Tarkwa)	Earthen pond	3 ponds (0.2 ha each), 3 ponds (0.05 ha each), 7 ponds (0.01 ha each)	0.5 tonnes
Karbo	Sunyani	Earthen pond	2 (0.1 ha), 1 pond (0.05 ha)	0.37 tonnes
Takyi grow out and fingerling production farm	Sunyani	Earthen pond	2 ponds (0.1 ha each), 1 pond (0.2 ha) and seven fingerling production ponds 6 sized 100 m^2 and 1 of 200 m^2	0.23 tonnes
Nkrumah	Sunyani	Earthen pond	1 pond (0.07 ha), 1 pond (0.06 ha)	0.25 tonnes
Tonku and	Sunyani	Earthen pond	1 pond (0.032 ha), 1 pond (0.03 ha). Also fingerling production ponds of 270 m^2, 60 m^2 and 50 m^2	0.008 tonnes
PAC	Kona-Odumase	Earthen pond	2 ponds (0.11 ha each), 19 ponds (0.036 ha each). Fingerling production facilities as follows, concrete: 4 (50 m^2), 2 (48 m^2 and 18 m^2), 10 (10 m^2); fibreglass: 5 (4 m^2), 10 (2 m^2), 10 (0.5 m^2)	Only 400 000 fingerlings of tilapia produced due to rehabilitation works
Faith Heroes	Asutuare	Earthen pond	3 ponds (1 ha, 0.29 ha, 0.23 ha)	3 tonnes
Ansong	Asutuare	Earthen pond	3 ponds (0.36 ha each), 2 ponds (0.09 ha each)	0.15 tonnes
Annan	Winneba	Earthen ponds under rehabilitation	19 ponds of various sizes totalling 1.23 ha	0.6 tonnes
Lee's farm	Akosombo	Fish cage	50 fish cages (6 x 5 x 5 m^3 each)	85 tonnes
Sang-you farm	Akosombo	Fish cage	60 fish cages (6 x 5 x 5 m^3 each)	102 tonnes
South Senchi Solidarity group	Senchi	Fish cage	4 cages (5 x 4 x 4 m^3 each)	2 tonnes
Dim fish farmers group	Dim (Afram Plains)	Fish cage	2 cages (5 x 4 x 4 m^3 each)	0.8 tonnes

Source: Field survey (2010).

3. RESULTS

3.1 Review of current feed use and feed management practices

3.1.1 Type of feeds

A range of feed types were recorded during the farm survey; these included commercially produced feeds, farm-made feeds, and supplemental feeds (agricultural by-products). Commercially produced feeds are currently imported from nine countries (Table 4), and two are being produced locally. Various sizes of floating pelleted feeds are imported for grow-out culture, and powdered feeds are imported for fry production. Feed is delivered in air-tight bags ranging in weight from 25.0 to 45.2 kg/bag. The proximate composition of the feed is provided for some but not all of the imported feeds. The local commercially prepared feeds are placed in feed bags that are not airtight and are supplied in 1.0 kg and 25.0 kg bags. Pelletizing is undertaken by hand, and thus pellet sizes are not uniform and the feeds tend to have a high percentage of fines. Farm-made feeds are stored in bags or jute sacs that are not airtight. To prevent the feeds from deteriorating and becoming mouldy, the feeds are made in small batches and are not stored for long periods of time.

3.1.2 Commercial feeds

Commercially produced feeds are imported into the country from Israel, the Netherlands, Egypt, Singapore, Indonesia, Denmark, Brazil, China and Viet Nam (Table 4). The imported feeds include fry, broodstock and grower formulations**.** Starter feeds have been imported from Denmark, Brazil and Israel. Fish feeds are not imported by the government. All the imports are made by the private sector. All the imported grower feeds are extruded floating feeds. Powdered fry feeds are also imported for fingerlings. Pellet sizes range from 0.3 mm to 6 mm. Two locally produced feeds are also available, with the trade names Aqua feeds and Aqua Engine. In recent years, commercial fish feed imports into Ghana have been increasing (Table 5).

TABLE 4
Country of origin of fish feed pellets available on the Ghanaian market

Country of origin	Feed name	Feed pellet size (mm)
Singapore	Inter quality (premium quality) 7002 feed	2, 4, 6
Indonesia	P. T. Matahari Sakti	4, 6
Viet Nam	Inter Quality Premium (Vasafeed Co. Ltd)	2, 4
Israel	Ranaan feed	2.5, 4.5
Denmark	Aller Aqua feed	0.3, 0.5, 0.7, 1, 1.5, 1.8, 2
Egypt	-	1, 2, 4, 6
Brazil	Pira Alevino feed, Proaqua (Nuton Alimentos Ltd.)	2, 4, 6
China	-	-
Netherlands	Coppens	3, 4.5

Source: Fisheries Commission (2010).

TABLE 5
Tilapia aquafeed imports (2006–2009)

Year	2006	2007	2008	2009
Quantity (tonnes)	21.5	235.0	126.1	518.7

Source: Fisheries Commission (2010).

3.1.3 Nutrient composition of commercial feeds

The proximate composition of the imported feeds that are available in Ghana is presented in Table 6. The protein contents ranged between 30 and 40 percent, and the lipid between 4.5–10 percent. The moisture content of the feeds ranged between 5.1–11 percent although most of the feed manufacturers did not provide the moisture content. It was evident that the labelling of some of the feeds was not sufficient to provide the farmers with the necessary information required to assess the suitability of the feeds. For example, the Aqua Engines feed only provided information pertaining to the protein content of the feed and provided no additional proximate composition data.

TABLE 6

Proximate composition and other nutrients in some of the commercial fish feeds in Ghana

Nutrient	Inter Quality Premium quality	Inter Aqua Feed	Coppens (Type 1)	Coppens (Type 2)	Ranaan (Type 1)	Ranaan (Type 2)	Aqua Engines
Moisture (%)	√	11	5.1	-	-	-	-
Crude protein (%)	30	30	40	34	30	30	32
Crude lipid (%)	4.5–5.0	5	10	10	4.5	4.5	√
Crude fibre (%)	6	6	-	3	√	5.5	√
Ash (%)	16	16	6.7	6	√	6.9	√
Premix (%)	-	-	-	-	-	-	√
Common salt (%)	2.5	2.5	0.1	0.2	-	-	-
Lysine (%)	-	-	-	-	1.6	1.6	√
Methionine (%)	-	-	-	-	1.0	-	√
Copper (mg/kg)	-	-	-	-	√	3	-
Vitamin A (IU/kg)	-	-	1 500	-	-	4 500	-
Vitamin D^3 (IU/kg)	-	-	-	-	√	1 050	-
Vitamin C (mg/kg)	-	-	150	150	√	90	-
Vitamin E (mg/kg)	-	-	200	200	√	120	-
Phosphorus (%)	-	-	0.9	0.7	-	-	√
Calcium (%)	-	-	0.8	1.0	-	-	√
Preservatives	-	-	-	E 280	-	-	-
Antioxidants	-	-	-	E 324, E 321	-	-	-

Source: Feed labels of commercial feeds available in Ghana.
Notes: √ = presence of the component; - = component not indicated.

The inadequate feed composition data provided to the farmers is largely due to the fact that the Fisheries Commission requires feed importers only to declare the tonnage of feed imported; providing proximate compositional data is not a statutory requirement.

3.1.4 Ingredients used in commercial feeds

Fishmeal and soybean are the primary protein sources used in all the imported feeds (Table 7). Other ingredients listed include rice bran, cereal meals, fish oil, and vitamin and mineral premixes. The feed ingredients used in the locally produced feeds include fishmeal, soybean, wheat bran, rice bran and vitamin and mineral premixes. The fishmeal used in these formulations is imported. The locally manufactured feeds are sinking feeds.

TABLE 7
The ingredient composition of selected commercial feeds

	Fishmeal	Soybean	Fish oil	Palm oil	Rice bran	Maize	Wheat	Premix	Wheat bran
Inter Quality Premium quality 7002 feed (imported)	√	√	√		√			√	
Ranaan feed (imported)	√	√				√			√
Aqua Engine (local)	√	√		√				√	√
Aqua feed (local)	√	√	√		√			√	
Coppens (imported)	√	√	√	√			√	√	

Source: Field survey (2010).

Note: √ = presence of the ingredient in feed.

3.1.5 Feed prices

Imported aquafeeds are exempt from import duties and value added tax (VAT); this is due to the Government policy of maintaining low prices for agricultural inputs and stimulating sectoral development. Retail feed prices are presented in Table 8. The price of grow-out feeds ranged between US$0.72/kg for a locally produced feed containing 32 percent protein to US$1.60/kg for an imported feed containing 30 percent protein. Starter feeds for fry and fingerlings were imported by one supplier. The fry and fingerling feeds are more expensive and contained a higher protein content than the grow-out feeds. The fry feed cost 2.59 US$/kg (48 percent protein), and the fingerling formulation cost US$1.87/kg (40 percent protein).

TABLE 8
The price of grow-out and starter feeds

Feed	Price		Protein (%)	Pellet size (mm)	Location of retailer
	GHS/kg	US$/kg			
Inter Quality Premium quality 7002 feed	35/25*	1.01	30	2, 4	Takoradi
Ranaan feed	36/20	1.30	30	2, 4.5	Accra Sunyani
Ranaan feed	45.2/20	1.60	30	4.5	Tarkwa
Ranaan feed (starter - fry)	72/20	2.59	48	0.3–0.6; 0.6–0.9	Ashaiman
Ranaan feed (starter - fingerling)	52/20	1.87	40	2	Ashaiman
Aqua Engines**	1.0	0.72	32	2, 4	Accra
Aqua feed**	25/25	0.72	-	-	Accra
Inter Aqua Feed	35/25	1.01	30–35	4.5	Accra
Inter Aqua Feed	39/25	1.15	-	-	Accra
Coppens	37.8/15	1.81	40	3, 4. 5, 6	Akuse

Source: Field survey (2010).

Notes: *35 GHS (Ghanaian Cedi) per 25 kg bag; Bank of Ghana exchange rate: US$1.00 = GHS 1.39 (19/5/2010); ** locally-produced feed.

3.1.6 Supplemental feeds

Supplementary feeds are either presented in the form of single ingredients, simple mixtures of powdered ingredients, or ingredients compounded into doughs or pellets. The farm-made feeds recorded in the present study were used as complete feeds; however, it was evident that they could not supply all the nutrient requirements of the fish. The farmers maintained their fish stocks on the feeds prepared on their own farms.

3.1.7 Fertilizers

Based on the results of the case study, the application of the pond fertilizers - both organic and inorganic - is poorly executed by the farmers, and their effect on water quality and fish production is poorly understood. The efficacy of their use is not monitored, and the farmers demonstrated that they were unable to estimate the level of primary productivity in their ponds.

Nine of the pond farms in the survey used organic manures (mainly chicken droppings, pig dung or cow dung and wood shaving mixture in occasional cases, Table 9). These manures were used at various application rates, and were applied to the pond bottoms prior to filling and during the production cycle. In one farm, approximately 25 kg of the semi-dry chicken manure and wood shaving mixture is placed in a polythene bag. Small holes are made in the bag, and it is placed in the corner of the pond, enabling the nutrients to leach into the pond. The wood shavings remain in the sac. The bag is left in the pond until the pond waters turn green. Some farmers applied both organic and inorganic fertilizers; these were applied during the culture period, not during pond preparation. The farmers exhibited a minimal understanding of the rationale behind their fertilization regimes, and only one farmer indicated that he fertilized his pond to increase primary productivity. A second farmer indicated that fertilizers increase fish production. The farmers added hydrated lime to their ponds at 0.35–3.5 tonne/ha/year (Table 9).

TABLE 9
Lime and organic manure application rates in selected farms

Farm name	Lime		Manure		
	Rate of application (tonnes/ha)	Price (US$/kg)	Rate of application (tonnes/ha/year)	Price (US$/kg)	Remarks
Ashaiman	0.35	0.29	No use reported	-	Green pond water
Achampong	1.0	0.5	2.0	Obtained free of charge	Green pond water
Dotsu	1.0	0.5	2.0	Obtained free of charge	Green pond water
Ansah	No use reported	-	No use reported	-	-
Akrofi	1.0	0.5	2.0	Obtained free of charge	Green pond water
Vikwam	1.0	0.5	2.0	Obtained free of charge	Green pond water
Karbo	No use reported	-	4.0	0.03	Green pond water
Takyi	No use reported	-	4.0	Obtained free of charge	Green pond water
Nkrumah	No use reported	-	4.0	0.03	Green pond water
Tonku	Wood ash; quantity not reported	-	50 birds/400 m^2 (i.e. 1 250 birds/ha)	Obtained free of charge	Green pond water
PAC	1.0	0.36	0.37	Obtained free of charge	Green pond water
Faith Heroes	3.5	0.29	1.1	0.14	Light green pond water
Annan	No use reported	-	No use reported	-	-

Source: Field survey (2010).

3.1.8 Farm-made feeds

Of the fourteen pond farms surveyed, only three depended solely on commercially manufactured aquafeeds. Six of the remaining farmers based their formulations on gross inclusion rates (weight), but did not take into consideration the nutritional qualities of the ingredients. The other five pond farmers in the survey did not apply fixed ratios of the ingredients that they used in their formulations. On some farms, buckets were used to measure the quantity of the ingredients used in the formulations, and the ratio of ingredients used in the feeds varied between production batches. Evidently, the formulations depended on the availability of finance to purchase feed ingredients - in particular fishmeal, which is the single most expensive feed ingredient. The cost of fishmeal imported from Brazil (64 percent protein) was US$1.43/kg. While some of the farm-made feeds are made into pellets using simple electric extruders (Figures 4 and 5), much of the feed is presented to the fish as wet doughs. In the rainy season, the feeds are presented to the fish as moist feeds because it is impossible to sun-dry them in the inclement weather. The prices of some raw materials available for use in farm-made feeds are provided in Table 10.

FIGURE 4
Electric fish feed pelletizer used to produce farm-made feeds

COURTESY OF E. DATUAH.

FIGURE 5
Pelletized farm-made feed being sun-dried on a plastic sheet

COURTESY OF E. DATUAH.

TABLE 10
Prices of local feed stuffs used as feed ingredients

Feed ingredient	Location	Price (US$/kg)
Wheat bran	Accra	0.16
Maize bran	Abosoo (Tarkwa)	0.40
Maize meal sweeping	Sunyani	0.07
Soybean	Sunyani	0.67
Groundnut peel	Tarkwa	1.99
Groundnut peel	Sunyani	0.12
Rice bran	Asutuare	0.07
Rice bran	Sunyani	0.07
Pito waste	Sunyani	0.12
Blood from abattoir	Sunyani	-
Poultry manure	Kona-Odumase	0.012

Source: Field survey (2010).
Notes: Ingredients come in various sized containers; prices have been converted to US$/kg.

The survey revealed that farm-made feeds using agricultural by-products and other feed ingredients were prepared using the following ingredients:

- Maize bran, wheat bran, ground whole soybean and fishmeal, plus starch as a binding agent.
- Maize bran, groundnut peel, fishmeal, plus starch as a binding agent (producing a 25 percent protein content diet).
- Maize bran, pito (Guinea corn chaff) waste, palm kernel chaff, groundnut husk and peel, fishmeal, plus starch as a binder (producing a 30 percent crude protein content diet).
- Groundnut peel and blood from a slaughter house, mixed with a commercial feed - 3 kg (groundnut peel and blood) were mixed with 2.25 kg of Ranaan feed.

The use of other plant based ingredients such as leaves, stems, fruits, flowers, stem and root tubers that have been previously been reported as suitable feed ingredients for farm-made feeds (FAO, 2005) was not reported in the present study.

All the commercial fish cage operators reported using commercially produced imported aquafeeds.

3.1.9 Pellet stability

All the farm-made feeds were crumbly and coarse to the touch when compared with imported manufactured feeds, which were more compact and stable. Even with the addition of a binder such as cassava starch, the farm-made feeds were poorly bound and quickly disintegrated when broadcast onto the surface of the water. Feed losses due to poor ingestion rates would likely be high using these poorly bound farm-made feeds.

3.2 Selection and choice of feeds

As manufactured aquafeeds are in short supply, farmers do not always have the opportunity to select the type of commercially produced feeds that they would like to use.

With regard to the preparation of farm-made feeds, the farmers indicated that they did not have access to information and knowledge that would enable them to prepare nutritionally balanced feeds. Of those feeds that were being prepared, it was evident that some would be unable to satisfy the nutritional requirements of the fish (Table 11). For example, one farmer produced feeds that comprised wheat bran and rice bran and no other ingredients. Only two farmers reported using mineral premixes in their formulations.

TABLE 11

Ingredients used in farm-made tilapia feeds

Farm	Fishmeal (%)	Soybean (%)	Blood from slaughter house	Groundnut peel	Maize bran	Wheat bran (%)	Rice bran	Pito waste	Palm kernel chaff	Premix (%)	Starch as binding agent
Ashaiman	√	44	-	-	-	8	-	-	-	0.05	-
Achampong	-	-	-	-	-	-	-	-	-	-	-
Dotsu	√	-	-	-	-	33.3	-	-	-	-	-
Ansah	-	-	-	-	-	-	-	-	-	-	-
Akrofi	√	-	-	√	√	√	-	√	-	-	-
Vikwam	√	-	-	√	√	√	-	-	-	-	-
Karbo	25	√	-	-	√	√	-	-	-	-	√
Takyi	30	-	-	√	√	-	-	-	-	-	√
Nkrumah	√	-	-	√	-	-	-	√	√	-	√
Tonku	-	-	√	√	-	-	-	-	-	-	-
PAC	√	-	-	√	-	√	√	-	-	-	-
Faith Heroes	-	-	-	-	-	√	√	-	-	-	-
Ansong	-	-	-	-	-	-	-	-	-	-	-
Annan	33.3	33.3	-	-	-	16.7	-	-	-	-	-

Source: Field survey (2010).

Note: √ = presence of the component .

3.3 Feed procurement, transportation and storage

Feed importation was managed solely by fish feed importers, who determined the feed price that they charge the farmers. Fish feed and other imported fish farm inputs are exempted from customs duties and VAT. With a letter of recommendation from the Ministry of Food and Agriculture to the Commissioner for the Customs, Excise and Preventive Service, the importer is allowed to clear imports without duty payments. It was noted that feed prices throughout the country were not related to the distance from the port of entry. This was attributed to the fact that the feed was delivered from different sources, was packed in different weight sizes, and had different formulations and pellet sizes (Table 8).

Imported feeds are transported in metallic containers from the ports to warehouses in the capital, Accra. Feed dealers either distribute the feed to locations closer to the farmers or, if larger quantities were required, transported the feed directly to the farmers.

In the central feed warehouses, the feeds are stored on pallets and are protected from spoilage (e.g. rodents). In contrast, on the farms the aquafeeds are not kept under optimal storage conditions. Feeds are often stored on the floor, and in some cases pallets are not used. This allows rodents to access the feed. In one case, the feed was kept in the open and covered with a tarpaulin at night. In inclement weather the feed would inevitably get wet and mouldy.

3.4 Review of existing feeding strategies

Both commercially produced and farm-made feeds were used by the farmers, either alone, in alternation, or in combination.

3.4.1 Feeding frequency

Fish were fed between two and four times a day (Tables 12 and 13). The daily ration was divided according to the feeding schedule shown.

3.4.2 Feeding rates

It was difficult to substantiate claims regarding the feed management practices. While mortalities occurred during the production cycle, farmers did not keep appropriate records. Pond farmers were generally advised by the Fisheries Officers to administer feed at rates equivalent to five percent of body weight of fish per day. However, many farmers fed at a constant rate throughout the production cycle, and were unaware that such practices were wasteful and would lead to low feed efficiencies. Knowledge regarding feeding tables is only becoming wide spread with the advent of commercial fish farming and the provision of feeding tables by some commercial feed producers. Feeding tables were only provided by one feed importer, and thus farmers in general were unable to accurately calculate feed rations.

3.4.3 Feed type

The commercial grow-out feeds were available in various pellet sizes, and in a powdered form for fry. The local farm-made feeds were either prepared as powders or pelletized using locally made pelletizers. The farm-made pellets were of uneven sizes and were broken into smaller pieces by breaking the extruded strands by hand. In order to feed juvenile fish or fingerlings, some farmers physically broke up the large commercially manufactured pellets into smaller pellets or powders. None of the farmers owned an extruder, and thus they were unable to make floating feed.

TABLE 12

Feed type and feeding frequency of feeds used in grow-out systems in surveyed farms

Farm	Type of feed	Commercial feed brand	Method of application	Feeding frequency (times/day)
Ashaiman	Commercial and farm-made feed	Ranaan feed	Broadcasting commercial and farm-made pellets	2 for brooders and 4 for fingerlings
Achampong	Commercial feed	Inter Quality Premium (Vasafeed Co. Ltd)	Broadcasting commercial pellets	2
Dotsu	Commercial and farm-made feed	Inter Quality Premium (Vasafeed Co. Ltd)	Broadcasting commercial pellets and farm-made dry powder	3
Ansah	Commercial feed	Inter Quality Premium (Vasafeed Co. Ltd)	Broadcasting commercial pellets	2
Akrofi	Commercial and farm-made feed	Ranaan feed	Broadcasting commercial and farm-made pellets	3 (4 for fingerlings)
Vikwam	Commercial and farm-made feed	Ranaan feed	Broadcasting commercial and farm-made pellets	2
Karbo	Commercial and farm-made feed	Ranaan feed	Broadcasting commercial and farm-made pellets	2
Takyi	Commercial and farm-made feed	Ranaan feed	Broadcasting commercial and farm-made pellets	2
Nkrumah	Commercial and farm-made feed	Ranaan feed	Broadcasting commercial and farm-made pellets	2
Tonku	Farm-made feed	-	Broadcasting farm-made pellets	2
PAC	Commercial and farm-made feed	Ranaan feed	Broadcasting commercial and farm-made pellets	3
Faith Heroes	Farm-made feed	-	Broadcasting farm-made pellets	2
Ansong	Commercial feed	Inter Aqua feed	Broadcasting commercial pellets	2
Annan	Commercial and farm-made feed	Yes (feed brand not reported)	Broadcasting commercial pellets and farm-made dry powder	4 (5 for fingerlings)

Source: Field survey (2010).

TABLE 13

Method of application of feeds and feeding frequency for tilapia fry on surveyed farms

Farm	Type of feed	Commercial feed	Ingredients in farm-made feed	Method of application	Feeding frequency (times/day)
Ashaiman	Commercial and farm-made feed	Ranaan	Wheat bran, fishmeal, soybean cake, vitamin premix	Broadcasting dry powder over the water	4
Annan	Commercial and farm-made feed	Inter Quality Premium	Wheat/rice bran fishmeal, soybean meal, premix	Broadcasting dry powder over the water	4
Vikwam	Commercial feed	Ranaan	Farm-made feed feeds not used	Broadcasting dry powder over the water	2
Akrofi	Commercial feed	Ranaan	Farm-made feed feeds not used	Broadcasting dry powder over the water	4

Source: Field survey (2010).

3.4.4 Feed additives

Some of the imported commercially prepared fish feeds contained additives (premixes), the composition of which was clearly indicated on the packaging material. The Ranaan feed listed the following as the additives in its feed: lysine, methionine, copper, vitamin A, vitamin D3, vitamin C and vitamin E. The rest of the feeds did not indicate the type of additives used in the feed.

3.4.5 Feeding methods, efficacy and possible improvements

Typically, the feeds were broadcast over the pond surface (Tables 12 and 13) and no attempt was made to concentrate the feed in a particular area of the pond. In only one case was a strategy adopted to minimize losses of sinking feed. In this case, the feed was broadcast in small quantities so that the fish could consume it before it sank.

On one farm, the farmer mixed an imported feed with a farm-made feed at a ratio of 1:1. On another, imported feeds were fed to the fish during the first two months of production; thereafter local farm-made feeds were used to rear the fish to market size. Where small feed pellets were not available, the farmers broke up the imported commercial pellets into smaller sizes for the fish to consume. One farmer reported alternating the farm-made feeds with the imported feeds. In all cases, there were no documented advantages to the feeding strategies adopted; however the farmers indicated that they were able to feed the fish for a long period of time with very few financial resources at their disposal.

3.4.6 Feed monitoring

Farmers monitored the growth of the fish visually, and did not record growth rates. Those farmers that used imported commercial feeds attributed their growth rates to the quality of feed and the fish seed. It was widely accepted that the imported feeds were more efficacious than the farm-made feeds.

4. DISCUSSION

Tilapia production in Ghana is increasing, and over 80 percent of the production is derived from cage farms where imported commercially complete feeds are used. All the imported feeds are extruded floating tilapia feeds. The imported feeds are relatively expensive and this was cited by some of the farmers as one of the reasons why they resorted to the use of farm-made feeds. Apart from fishmeal, the feed ingredients used in preparing farm-made feeds are not imported. Fishmeal and soybean comprise the primary protein sources that are used in the production of farm-made feeds. Blood meal from slaughterhouses was used in only one of the 14 farms surveyed, and this was as a result of its close proximity to a slaughterhouse. Wheat, maize and rice bran were the primary carbohydrate sources that were used in farm-made feeds. The nutrient composition of the ingredient sources was not a consideration in terms of formulation. Wheat bran was widely used because it is widely available throughout the country. Cassava is also widely available but at present it is not used in farm-made feeds as it has not been introduced to the farmers as a potential feed ingredient.

The farmers do not have extruders, and only three of the farms surveyed used locally-made mincers as pelletizers. To prepare the feed, the feed mixture is moistened and extruded through the mincer. The carbohydrate component of the feed meal provides the starch that acts as a binder. The feed is sun-dried, and the extruded strands are broken into smaller pieces that can be consumed by the fish. The pellets tend to be coarse and are not of uniform size.

Some of the farm-made feed is wasted during the feeding process when inappropriate pellet sizes are used and they are too small or too large to be ingested by the fish. Alternatively, feeds that have a large percentage of fines result in poor ingestion rates and feed is wasted as the fines disperse in the water column. At the Ashiaman farm,

the manager estimated that 10 percent of the feed was reduced to powder during the manual hand pelletizing process. The feed that sinks accumulates at the bottom of the pond, reducing water quality. The risk of water quality deterioration and an associated reduction in fish growth is ameliorated when the accumulation of organic matter is minimized (Ofori, 2001), or when the fish are cultured in cages where there is adequate water flow. The use of manures and chemical fertilizers in combination with formulated feeds has been well documented (Shroeder, 1973; Boyd, 1992). However, knowledge concerning the use of on-farm wastes for fish production in Ghana is limited (Owusu-Frimpong, 1989). As a result, farmers use both organic and inorganic fertilizers in a haphazard manner that is not related to water quality parameters. In addition, farmers do not measure the natural productivity in their ponds, and thus they are unable to modify their fertilizer use appropriately.

Local feedstuffs are cheap but are not widely available in sufficient quantities throughout the year. They are used mainly in extensive fish culture systems at the rural or subsistence level, and as on-farm feedstuffs (Ofori, 2001). The quality and quantity of nutrients available in each consignment varies according to the milling process. The local rice and corn mills do not produce by-products of the same quality during each milling process. Tilapia feed directly on these agro by-products. Ofori (2001) demonstrated that the use of rice in feeding tilapia resulted in nutrient enrichment of the water, which in turn influenced the production of phytoplankton on which the tilapia could feed. Commercial fish cage operations do not depend on these agro by-products as feed sources.

While the use of imported commercially complete feeds is popular, farmers are constrained by their high cost. To reduce these costs, farmers adopt a number of strategies. However, these do not take into consideration the slower growth and the reduction in income that may accrue to their adoption. The strategies adopted include:

- Reducing the size of the feed ration.
- Starting the production cycle by feeding commercially produced aquafeeds but then switching over to farm-made feeds during the latter stages of the production cycle.
- Pounding commercially imported feed into smaller pellets in a mortar to feed newly stocked fingerlings so that the farmer does not have to buy feeds of smaller pellet sizes, which are often more expensive.
- Those farmers feeding three times a day, including a fish cage farmer, indicated that feeding smaller quantities of feed more often resulted in reduced feed wastage.

The farmers did not maintain feed records, and thus it was not possible to verify the efficacy of their feed management practices

5. RECOMMENDATIONS

5.1 Feed production and management

On the small- to medium-scale farms, on-farm feed production and its use is not managed in a way that ensures maximum returns. The proximate composition of the feed is generally not considered. Feeding tables are not provided. Urgent attention is required on the part of farmers, extension officers and fisheries officers to rectify these shortcomings. They need to start to use feeding tables. Furthermore, they require access to information pertaining to the proximate composition of the feeds that they purchase.

5.2 Feed storage

In general feed storage facilities are poorly maintained and, in some farms feed was stored on the ground. Vermin often have access to the feed. Some feeds are kept for more than three months and are likely to have deteriorated in terms of nutrient composition and availability. Surveyed farmers found it very difficult to dry farm-

made feed during the rainy season, and the feeds often became mouldy. Those that used farm-made feeds did not optimize their feed use, leading to feed wastage. In such cases, improvements in feed management practices to avoid waste and negative impacts on water quality are required.

5.3 Research needs

The following research needs have been identified:

- Analyse the composition of farm-made feeds to determine whether the nutrient requirements of the fish are being met by the current formulations.
- Assess the feed conversion ratios (FCR) being attained under local farm conditions.

Farmers should be encouraged to take an interest in the development of the research agenda that will resolve these issues.

5.4 Legislative needs

To ensure that quality feed and feed ingredients are used, regulations are required to support efforts to ensure the certification of commercially imported feeds. By law, all feeds must provide labels outlining the nutrient composition of the feed; the manufacturers must provide feeding tables and provide an indication of the anticipated FCR. Feeds must be traceable.

5.5 Regulatory framework

There is a need for regular fish farm visits to inspect farm houses/feed stores to ensure that only certified feeds are being used by farmers. Guidelines outlining inspection procedures must be prepared to assure farmers of the legitimacy of the inspection processes.

5.6 Training

Farmer training is required to improve feed production and feed management practices. Farmers need to be taught to appreciate and understand the advantages associated with the use of good quality feed; to monitor fish growth and feed rations; to calculate FCR; to determine cost-benefit ratios; and to improve their feed formulations and choice of ingredients. It is also important to train the farmers to improve the natural productivity of their culture systems, and understand how natural productivity can improve yields. Farmers also need to be made aware of the dangers associated with overfeeding and the concomitant reduction in water quality. In this regard, non-governmental organizations and universities could provide some technical assistance in complementing government institutions to help in the development of aquaculture in Ghana. The capacity of farmer organizations should be strengthened, so that information pertaining to best management practices can be shared amongst them.

6. CONCLUSIONS

On-farm fish feed management practices are poorly understood by the farmers (e.g. the use of inappropriate feed rations leads to poor growth rates and reduced incomes). Farmers need training in terms of the preservation, storage and administration of feeds such that feeds are optimally used and profits are maximized. The review demonstrates that feed is not being stored properly by farmers and that the current farm-made feed formulations do not satisfy nutrient requirements. In this regard, there is a lot of feed wastage. Farmers do not maintain feed records and are thus unable to optimize their feed management strategies.

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On-farm feed management practices for three Indian major carp species (rohu *Labeo rohita*, mrigal *Cirrhinus cirrhosus* and catla *Catla catla*) in Bangladesh: a case study

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ABSTRACT

Three Indian major carps (rohu *Labeo rohita*, mrigal *Cirrhinus cirrhosus* and catla *Catla catla*) are considered prime aquaculture species in Bangladesh. Three basic production systems are in use, viz. broodstock and fry production systems, nursery systems and grow-out systems. Successful production in these systems is dependent on a number of factors; amongst these supplemental feed and its administration is an important consideration. In the context of improved extensive and semi-intensive aquaculture systems, the supply of nutrients through the application of supplemental feeds represents a pre-requisite for sustainable fish production. In order to determine the characteristics of supplemental feeding in major carp aquaculture, and to inform the development of recommendations to improve the current management paradigm, a field survey of the different production systems was conducted. The study was conducted in the four major production regions of Jessore, Mymensingh, Comilla and Rajshahi. Three questionnaires based on the different production systems were developed, pre-tested and used for conducting the survey. A total of 85 farmers were interviewed, and the information pertaining to different aspects of their production systems was obtained. This information included species selection, species composition, stocking densities, production levels, pond preparation and management practices, natural food production, the use of supplemental feeds, its preparation, presentation and storage. The collected data was synthesized and analysed. In the broodstock systems, variability was observed in terms of the species cultured and stock composition, broodstock management, and supplemental feed and feed management practices. All the hatchery operators had a common attitude towards the provision of supplemental feeds, either in the form of pellets or wet doughs. However, the farmers demonstrated a poor understanding of the genetics of broodstock management and nutrition. Geographically, farmers operating nursery systems applied similar species selection, stocking, rearing and supplemental feeding strategies. Typically, the farmers fed the fry with mustard oil cake – a protein source that is unable to

provide all the nutrients required for optimal growth. This widespread practice suggests that the farmers do not have a good understanding of the nutritional requirements of the fry. With respect to the farming practices used in the grow-out systems, it was found that species selection, stock composition, stocking densities and water management practices varied greatly between the farmers, and that there was a wide regional variation in supplemental feeding practices. The majority of farmers use supplemental feeds on a regular basis and only feed irregularly when financial constraints prevent them from buying feeds. Farm-made supplemental feeds, locally produced and industrially manufactured pellet feed are used. In general, farmers demonstrated a poor understanding of the nutritional requirements of the fish, the impacts associated with nutrient losses during feeding, the use of feed conversion ratios as a management tool, and the need for good on-farm record keeping.

1. INTRODUCTION

The feeding behaviour of the Indian major carps, namely catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus cirrhosus*) is species specific. *Catla catla* is a surface feeder; *Labeo rohita* is a mid-surface or column feeder, and *Cirrhinus cirrhosus* is a bottom feeder (Jhingran, 1991).

Mookerjee (1944) reported that all the Indian major and minor carps show cannibalistic behaviour as fry. According to Alikunhi (1952), large fry (or fingerlings) of catla, rohu and mrigal cannibalise their smaller conspecifics. Jhingran (1991) reported that the food and feeding behaviour of the hatchlings and fry of the Indian major carps differ markedly from those of the fingerlings and adults. George (1963) found that although the major carps ingest a variety of phytoplankton, zooplankton and higher aquatic plants, catla prefer to select plankton, mainly zooplankton, while rohu and mrigal prefer plant matter, including decaying plant materials. Azim *et al.* (2002), comparing the production of three Indian major carps, catla, rohu and orangefin labeo/kalbasu (*Labeo calbasu*) in periphyton-based polyculture systems, found that while the rohu grazed the periphyton, the catla consumed planktonic food organisms. Ranade and Kewalramani (1956) demonstrated that catla utilize animal food sources better than mrigal and rohu, and that rohu is less adapted to animal food sources than mrigal. Gut content analysis of catla and rohu shows a dominance of phytoplankton at the fry rearing stage (Dewan *et al.*, 1991).

Indian major carps are cultured throughout the country, and under various management regimes. In the past, farmers cultured them in ponds and oxbow lakes (local name: *baors*)[1] with little or irregular supplemental feeding. However, these systems did not supply sufficient feed to the fish. The poor feeding rates applied were attributed to a lack of knowledge pertaining to the nutritional requirements of the fish. With the development of science-based fish culture and its practices, farmers have become aware of the need to provide supplemental food to the fish.

A number of feed and feed management practices are used in Bangladesh. Some farmers depend on natural productivity to supply the nutritional requirements of the fish, while others provide farm-made supplemental feeds, either regularly or irregularly. Commercially made aquafeeds are available, but in many cases their quality is unknown or poor. Farmers use feed supplements such as hormones, enzymes, growth promoters and antibiotics but these additives are not certified by the relevant authorities. To protect the adulteration of products in the feed industry and to ensure the quality of feeds in the market, the Government of Bangladesh recently promulgated the Fish and Animal Feed Act, 2010 (Annex).

[1] Oxbow lakes (local name: baors) are semi-closed water bodies, which occupy the dead channels of the rivers in the moribund delta of the Ganges. Normally, an oxbow lake remains part of the river floodplain, to which it is connected by inlets and outlets (Hasan and Talukder, 2004).

2. METHODOLOGY

The study was carried out by conducting interviews at hatcheries, nurseries, and grow-out farms (Table 1). Three sets of questionnaires were developed, one for each farmer group. The interviewees were selected so as to provide a representative sample of farm sizes. In addition to these three groups, information was also collected from feed millers, aquafeed manufacturing companies, and feed dealers. Additional information was collected from other sources such as the scientific and grey literature.

TABLE 1
Number of stakeholders interviewed at different categories and the farm sizes

Stakeholders	Sample size	Farm size range
Hatchery operators	25	0.52 to 14.3 ha
Nursery operators	30	0.17 to 6.0 ha
Grow-out farmers	30	0.52 to 39.6 ha

Source: Field survey (2010).

Although Indian major carp culture is being practiced throughout the country, the major production activities tend to be clustered. Some areas specialise in hatchery and fry production, while others specialise in nursery and grow-out production.

Due to time constraints, it was not possible to visit farmers in all the districts where major carps are produced but farmers from the four most important culture regions were included in the study. In addition to their aquaculture activities, many of the farmers exploited alternative livelihood options, for example, terrestrial farming (e.g. poultry), and had minimal time to respond to the survey. Furthermore, farmers' education constrained data collection as many farmers were unable to clearly enumerate the management practices that they applied.

3. FEED AND FEEDING PRACTICES USED IN INDIAN MAJOR CARP PRODUCTION

Catla, rohu and mrigal are the main culture species in the region, and are normally cultured together. These species feed at different levels in the water column and rearing them in polyculture maximizes feed utilization (Jhingran, 1991; Ahmed, 1992). Although the Indian major carps represent the primary culture species, a number of exotic carps imported from China and Europe are also cultured. The inclusion of these exotic carps increases the competition for food with the Indian major carps. In order to minimise feed competition, most farmers supplement their natural pond productivity with farm-made aquafeeds. The feed and feed management practices vary according to the production phase, viz. broodstock, fry, and fingerling/yearling production.

3.1 Feeding and the rearing of Indian major carp broodstock

In Bangladesh there are 845 private sector and 77 public sector hatcheries. Combined, these hatcheries produce 624 805 kg of fry (both indigenous and exotic carps) per annum. An additional 4 370 kg of fry is wild caught from the rivers (DoF, 2012). The production of high quality broodstock requires the use of good husbandry protocols. In recent years, the quality of seed produced has deteriorated as a result of poor quality broodstock and poor management protocols. Many hatchery operators are unaware of the importance of genetics in broodstock selection and, as a result, inbreeding and hybridization is commonplace. This results in increased mortality rates, reduced growth characteristics, deformities, and increased vulnerability to disease.

3.1.1 Pond preparation for broodstock conditioning

The survey revealed that all the hatchery operators prepared their broodstock ponds using organic and inorganic fertilizers (Table 2). The farmers reported using different pond sizes, ranging from 0.13 ha to 0.80 ha (Figure 1). Ponds are drained and dried once a year to eradicate predatory fish species. In those cases where it is difficult to completely drain the ponds, the farmers apply piscicides, including rotenone, phostoxin, and celphos. After drying or poisoning the ponds, lime is applied throughout the pond and dyke area at 125 to 250 kg/ha followed by cow dung at 250 to 1 250 kg/ha. Cow dung is applied at higher rates in newly constructed ponds, or in ponds in which the bottom clay has been removed. Inorganic fertilizers such as urea and triple super phosphate (TSP) are applied at 25 to 50 kg/ha and 37.5 to 187.5 kg/ha respectively. Some farmers prefer to apply muriate of potash (MP) at 12.5 to 37.5 kg/ha in ponds that have high clay contents. In addition to these practices and to increase primary productivity, some farmers apply mustard oil cake and cow dung at 750 to 1 125 kg/ha. On completion of the process, the ponds are filled with underground water from shallow tube wells or with rain water. The ponds are filled to a depth of four to five feet (~1.2–1.5 m). During the rainy season, the water depth of the ponds sometimes increases to eight to nine feet (~2.4–2.7 m). After administering the fertilizers, and once the pond waters mature, the juveniles or brood fish are stocked. The stocking density of brood fish varies, with total fish biomass was reported to be between 2 000 to 5 000 kg/ha.

FIGURE 1
Carp hatchery (left) and broodstock pond (right)

COURTESY OF FAO/M.R.I. SARDER.

TABLE 2
Commonly used organic and inorganic fertilizers

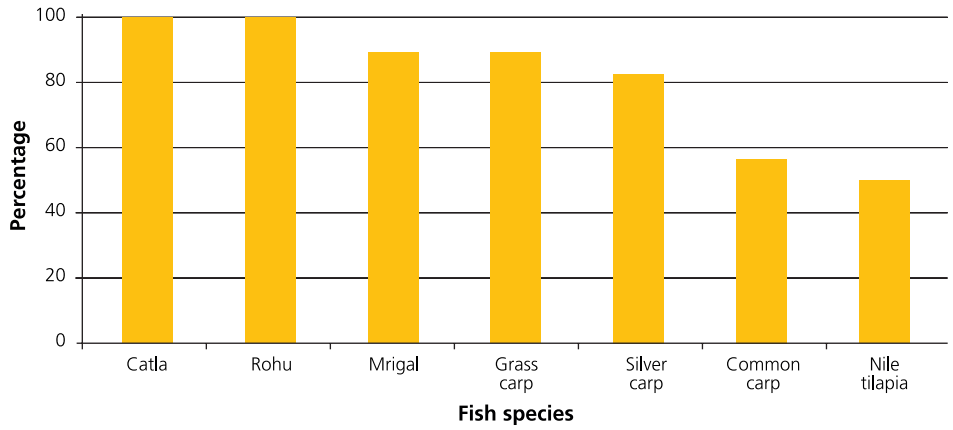
Ingredient	Cost (US$/tonne)	Application rate (kg/ha)
Lime (calcium carbonate)	174.0	125–250
Cow dung	14.5	250–1 250
Poultry litter	14.5 (wet) 29.0 (dry)	625–875 500–625
Triple super phosphate (TSP)	333.3	37–187
Urea	188.4	25–50
Muriate of potash (MP)	333.3	12–37

US$1= Bangladesh Taka (BDT) 69.00.
Source: Field survey (2010).

3.1.2 Fish selection and stocking

In the past, only three or four of the major carps (catla, rohu, mrigal and orangefin labeo/kalbasu) were reared together. More recently, exotic carps and catfishes have also begun to be stocked. Currently, 18 species are stocked in various combinations, usually in combinations of four to ten species. The survey revealed that seven fish species, namely catla, rohu, mrigal, silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*), kalbasu and silver barb (*Barbonymus gonionotus*) were the most common species being cultured (Figure 2).

FIGURE 2
Occurrence of the major culture species used in polyculture systems in Bangladesh

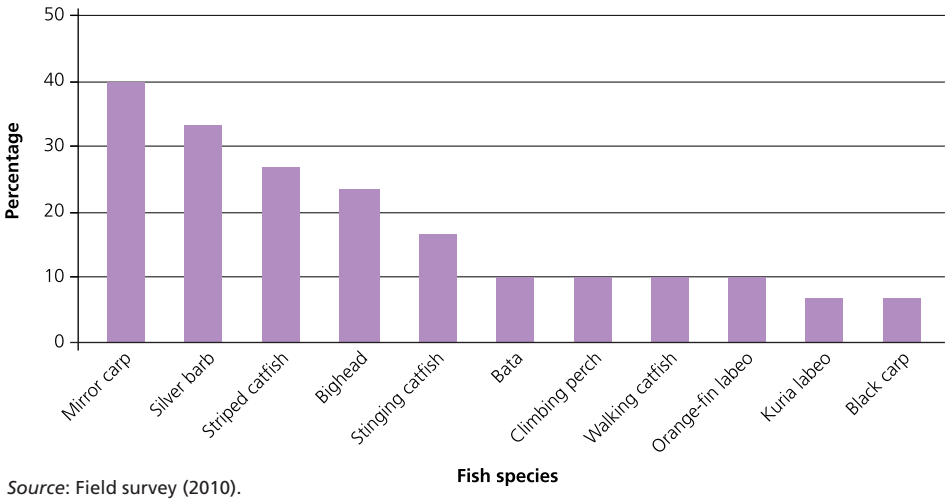


Source: Field survey (2010).

In addition to these commonly stocked species, other species, including a mixture of indigenous and exotic carps and catfishes are also stocked (Figure 3).

In Jessore (southern Bangladesh), catla, rohu and mrigal were commonly stocked and reared. Some hatchery operators in this region reported separating the catla from the other species. In addition, silver carp, grass carp, silver barb, kalbasu, and

FIGURE 3
Occurrence of other species (indigenous and exotic carps and catfishes) in polyculture systems in Bangladesh



Source: Field survey (2010).

sometimes common carp, black carp (*Mylopharyngodon piceus*) and bata (*Labeo bata*), were reared in combination with the major carps. The water depth of the ponds in this region was maintained at approximately six feet (~1.8 m). Outside the breeding season, it was often reported that hatchery operators stocked their fish at high densities (3 500 to 7 500 kg/ha). With the onset of the breeding season, densities were reduced and feeding was increased to promote gonadal development. In some instances the catla were reared separately because, in comparison with the other species, they fare best at lower stocking densities. In eastern Bangladesh (Comilla region), the major carps were reared with silver carp, grass carp, silver barb, bighead carp (*Hypophthalmichthys nobilis*), kuria labeo (*Labeo gonius*) and striped catfish (*Pangasianodon hypophthalmus*). One hatchery owner reported rearing only catla and striped catfish together.

3.1.3 Broodstock nutrition and feeding

Once the ponds have been prepared, filled and matured (green water) they are stocked with brood fish (1.5 to 5.0 kg). The newly stocked fish graze the natural productivity of the ponds, and are supplied with supplemental feeds on a regular basis. Supplementary feeding is an essential component of the broodstock management protocol. To enhance the growth a balanced diet containing at least 25 percent protein should be provided. DoF (2006) suggested that for growing out broodstock from fish weighing 1 kg, a supplementary feed comprising fishmeal, mustard oil cake, soybean meal, rice bran, wheat bran, wheat flour, molasses and a vitamin pre-mix should be supplied at a daily rate of five percent of body mass (Table 3, Feed I). DoF (2006) also suggested that for rearing broodstock, a supplemental feed comprising wheat bran/rice bran, mustard oil cake, fishmeal, wheat flour, molasses and Vitamin E should be provided once a day at two to three percent of total body mass (Table 3, Feed II). Mazid *et al.* (2002) reported that an appropriate broodstock formulation comprised fishmeal, soybean meal, rice bran, wheat bran, mustard oil cake, sesame oil cake, wheat flour, molasses, and a vitamin and mineral premix (Table 3, Feed III). Feed III (Table 3) was reported to produce the best growth and reproductive performance in rohu and catla, compared to the results of using feed formulations I and II. The survey revealed that although all the farmers provided supplemental feeds, their preparation varied. With the exception of those in Jessore, the farmers preferred to use farm-made feeds using locally available ingredients such as mustard oil cake, wheat bran, rice polish/bran, fishmeal, molasses, and soybean meal. In contrast, hatchery operators in Jessore region used manufactured pelleted feeds. The ingredients that are commonly used in the preparation of farm-made feeds are presented in Table 4. To enhance gonadal development, most of the hatchery operators use vitamin and mineral mixtures; a number of companies provide vitamin and mineral mixtures (Table 5).

TABLE 3
Common dietary formulations used for broodstock rearing: farm-made feeds

Ingredients	Feed I (%)	Feed II (%)	Feed III (%)
Fishmeal	16	15	15
Mustard oil cake	10	30	20
Soybean meal	24	-	12
Rice bran	20	45	16.7
Wheat bran	19	-	14.5
Wheat flour	5	5	3
Molasses	5	4	5
Vitamin pre-mix	1	1	1
Sesame oil cake	-	-	12.8

Source: Field survey (2010).

TABLE 4
Common dietary ingredients used in broodstock feeds: farm-made feeds

Ingredient	Inclusion level (%)	Price (US$/tonne)
Mustard oil cake	30–50	362
Wheat bran	10–20	232–261
Wheat flour	10	290
Rice bran/polish	20–30	174–218
Corn flour	10–20	290
Soybean meal	5–10	580–608
Fishmeal	15	580–652
Meat and bone meal	5	290
Molasses	5	174–218
Crushed snail shell	1	145
Vitamin premix	0.5–1.0 g/kg feed	3 623
Biscuit residue from a bakery*	4–5	258
Common salt*	0.5	170
Di-calcium phosphate*	1	170 (local) 542 (imported)
Binder*	0.5	2 570

US$1= Bangladesh Taka (BDT) 69.00
*Ingredients that are used by some hatchery operators in Jessore region to improve feed quality.
Source: Field survey (2010).

TABLE 5
Vitamin, mineral mixtures and supplements

Company	Product	Price (US$/kg)
Novartis Animal Health, Novartis (Bangladesh) Limited	i) Megavit-Aqua (vitamin-mineral and amino acid supplement) ii) AQUA Boost (Non-antibiotic growth promoter)	i) 3.77 ii) 5.50
ACI Livestock and Fisheries (Aqua Products Profile)	i) ACImix super-fish (vitamin, mineral and amino acid enriched premix) ii) AQGRO-G iii) AQGRO-P iv) AQGRO-L (Herbal growth promoter)	i) 1.60 ii) 4.05 iii) 2.60 iv) 2.60
Eon Animal Health Products Ltd. EON Group*	i) EON Fish Grower ii) Nutricell Aqua-Non-antibiotic growth promoter iii) Ecolite (The health stone) iv) Timsen (Biocide)	i) 2.29 ii) 6.52 iii) 0.55 iv) 68.98
ACMY Limited	Vitamix F Aqua premium	4.06
Renata	Vitamin premix (Rena Fish)	3.77
Navana Pharmaceuticals Ltd.	Aquavit Plus	3.61
Agronest (Pvt.) Ltd. Dhaka, Bangladesh	Zanvit, Fish grow (Fish feed premix)	3.91

*www.eongroup.net.bd
Source: Field survey (2010).

3.1.4 Feed preparation

Farm-made feeds are prepared by weighing the feed ingredients according to a defined formulation, and mixing them homogenously. If mustard oil cake is used, it is first soaked in water for at least 24 hours. Once soaked, the other ingredients are added, and the ingredients are mixed and kneaded into a wet dough. The mixed feed is fed to the fish by distributing it between several locations across the pond. The supplemental feed is provided at two to five percent of body mass per day, and at between 10.00 to 13.00 hours (Figures 4, 5, 6 and 7). The feed is normally consumed within 30 to 60 minutes. The protein content of the supplementary feed was unknown as the hatchery operators do not determine the proximate composition of their feeds. However, they assumed that it contained between 20 to 25 percent protein.

FIGURE 4
Water soaked mustard oil cake (left) and fishmeal (right)

COURTESY OF FAO/M.R.I. SARDER.

FIGURE 5
Mixture of soaked mustard oil cake, and dry wheat bran and fishmeal (left) and hand mixing of the ingredients with water (right)

COURTESY OF FAO/M.R.I. SARDER.

FIGURE 6
Homogenously mixed wet feed (left) and dough preparation (right)

COURTESY OF FAO/M.R.I. SARDER.

FIGURE 7
Wet doughs (left) and feeding the wet dough (right)

COURTESY OF FAO/M.R.I. SARDER.

The majority of the hatchery owners believed that the quality of their farm-made feeds was superior to that of the manufactured feeds available in the market. They assumed that by formulating their own feeds, they had a better control over the quality of the feed ingredients used. Supplemental farm-made feeds cost US$290 to 362/tonne. In comparison, manufactured aquafeeds cost between US$362 to 435/tonne. The majority of the hatchery operators indicated that in comparison to manufactured aquafeeds, the poor binding properties of the farm-made supplemental feeds resulted in increased levels of wastage - typically between 15 to 20 percent.

In Jessore region, all the hatchery operators used supplemental feeds that were based on locally available feed ingredients. Typically, a private fish and poultry feed company would formulate the feed using ingredients such as mustard oil cake, rice polish, wheat bran, fishmeal, corn flour, soybean meal, vitamins, minerals and other feed additives e.g. probiotic enzymes, hormones etc. The company sold the feed ingredients and provided a feed manufacturing service to farmers. In many cases, the farmers would request the use of specific ingredients and formulations that would then be prepared accordingly.

The 'Maliha Enterprise' feed mill was an example of a feed mill providing these services. Feeds produced in the mill were supplied to the hatcheries in 25 or 50 kg bags. The hatchery operators stored the pellet feed in a storeroom on a cement floor, beneath jute carpets, or on a wooden platform. Storage periods of up to 25 to 30 days were reported. Although the proximate composition of the feeds was unknown, they were assumed to contain 20 to 25 percent of crude protein. The feed cost was US$362/tonne. The pelleted feed was fed at two to three percent of body weight per day, applied either in a single ration or divided between two per day. Some hatchery operators reported using farm-made pelleted feeds in the morning, and commercially produced feeds in the afternoon.

All the hatchery operators provided supplemental feeds to their brood fish on a regular basis. Supplemental feeding was not undertaken on cloudy or extremely hot days. Supplemental feeding was also suspended after heavy rainfall or when the presence of toxic gases was noted. Gases such as hydrogen sulphide and carbon dioxide in the pond bottom sometimes occur as a result of the decomposition of leftover or uneaten feed. To remove the toxic gases, horra (a long rope with number of small weights attached) are pulled along the bottom of the pond and, where necessary, clean water is added to the pond. In general, the hatchery operators take responsibility for all aspects of pond management; however, in some cases they use hired labour.

To maintain the natural productivity of the pond systems, hatchery operators applied inorganic fertilizers, especially urea and TSP, to their ponds at 15 to 30 day intervals. In this regard, cow dung was applied irregularly and typically at intervals of two to three months. Hatchery operators in the Jessore region use composted manure to maintain the natural productivity of their pond water. Table 6 presents typical ingredients used to prepare composted manures.

TABLE 6
Composition of typical composted manures used in hatchery ponds

Case 1		Case 2	
Ingredient	Quantity (kg)	Ingredient	Quantity (kg)
Cow dung	200	Cow dung	200–400
Mustard oil cake	50	-	-
Rice polish	25	-	-
TSP	10	TSP	20–50
Urea	10	Urea	10–12

Source: Field survey (2010).

3.1.5 Preparation of composted manures

Composted manure is prepared by placing the materials (excluding urea) in an earthen pit or a cement bowl, mixing well, and leaving to decompose for 10 to 15 days. After 12 days the urea is added, and the mixture is left for a further three days. After about 15 days of decomposition, the compost is spread over the pond surface at the rate of 75 to 150 kg/ha, and at seven to ten day intervals. After applying the manure, the availability of phytoplankton and zooplankton in the pond water was established by sampling the pond water in a glass receptacle that is held against the sun to visually observe the plankton or sampling the plankton using a scoop net or a piece of fine cloth.

None of the respondents used Secchi disks to estimate the level of primary productivity, and all the respondents opined that plankton blooms did not normally occur in the broodstock ponds as the plankton was continually eaten by the fish. When plankton blooms did occur, dipterex was applied at 7.5 kg/ha, applied weekly for a period of three to four weeks.

3.2 Fry production and feeding

All the hatchery operators produced fry of the Indian major carps through hypophysation. Matured males and females were collected from the rearing ponds and placed in a cistern. The male and female fish were induced with pituitary gland (PG) extract and/or human chorionic gonadotropin (hCG) hormone. Eggs were collected by stripping the females immediately after ovulation. The fertilized eggs were transferred to an incubator for hatching.

Breeding may also be undertaken by placing the induced males and females in a circular spawning tank. The males and females release their gametes naturally, and the fertilized eggs are retrieved from egg collectors that are fitted to the outlet of the circular tank. The fertilized eggs are placed in an incubator for hatching. The larvae of the major carps normally hatch within 18 to 24 hours after fertilization, and start feeding after the complete absorption of the yolk sac – this usually occurs within 32 to 48 hours of hatching. The fry are fed hard-boiled chicken egg yolk that is mixed with water and spread over the surface waters. Plankton are also collected from pond waters and fed to the fry. In some cases, a specialized supplemental mixed shrimp feed was

used as a nursery feed. After five days, the fry are ready for sale to the nursery farmers and are sold in oxygenated polythene bags.

Despite the presence of natural feed in the ponds, hatchery operators provide supplemental feed to their broodstock every day. The type and ingredient composition of these feeds varied. Many hatchery farmers had a poor understanding of the nutritional requirements of their broodstock. The majority chose to provide farm-made supplemental feeds as wet doughs but some used locally produced pelleted feeds. It was evident that there was a need to improve the quality of the supplemental feeds used, and in this regard, the hatchery farmers need to be provided with training in pellet manufacturing technologies, storage, and feeding. In addition, the establishment of small feed mills close to the hatcheries should be encouraged.

3.3 Nursery production systems

Private nurseries produce most of the Indian major carp fingerlings used in aquaculture in Bangladesh and there are 10 802 private carp nurseries. Their size ranges between 0.17 ha to 6.0 ha. In addition, 35 Government Fish Seed Multiplication Farms provide fry to the famers. In 2010–2011, approximately 8 204 million fingerlings were produced (DoF, 2012). Between 2009 and 2010, it was estimated 465 396 kg of fry were produced – this level of production is more than enough to meet the demand. Nevertheless, at times the production in the sector is constrained by a lack of quality fingerlings. It is assumed that only 20 to 30 percent of fry survive to the fingerling stage. The water depth of the nursery ponds is maintained at three to five feet (~0.9–1.5 m).

3.3.1 Pond preparation techniques

Both seasonal and perennial ponds are used as nurseries (Figure 8). Seasonal ponds are prepared for nursery production at the end of the winter season when they dry out; piscicides are not used in this process. In contrast, the perennial ponds are prepared by dewatering or by applying toxins such as rotenone, phostoxin and celphos to kill carnivorous or unwanted fish. After drying or poisoning the ponds, lime and cow dung are applied at rates of 250 to 500 kg/ha and 1 250 to ≥2 500 kg/ha respectively. Liming and manuring are undertaken five to seven days prior to stocking. Inorganic fertilizer, such as urea and TSP, may also be applied at rates of 25 to 50 kg/ha and 12.5 to 37.5 kg/ha respectively. In addition, muriate of potash (MP) and mustard oil cake may also be applied at rates of 12.5 to 17.5 kg/ha and 62.5 kg/ha respectively.

FIGURE 8
The owner and workers of a nursery with a net (left) and a typical nursery pond (right)

COURTESY OF FAO/M.R.I. SARDER.

To enhance plankton production some farmers in the Mymensingh region use molasses and wheat flour mixes that are added to the ponds three days before stocking. The molasses and wheat flour are added at rates of 40 to 43.75 kg/ha and 85 to 87.5 kg/ha respectively. The day before stocking a pesticide, such as dipterex or sumithion, at 0.15 to 0.25 ppm is added to the ponds to eradicate insects and large zooplankton species such as cladocerans. After stocking, some farmers applied urea and TSP at 25 kg/ha. Applications were made three times a month and designed to promote primary production. After stocking, farmers apply TSP and urea at 25 and 20 kg/ha/month respectively. When plankton blooms appeared in the ponds, the farmers reported adding lime and MP at rates of 50 to 62.5 kg/ha and 0.5 to 2.5 kg/ha respectively. In addition, to improve water quality, new water may be added to the ponds and the blooms may be removed using fine nets, or by adding dolomite (natural calcium magnesium carbonate) at 25 kg/ha. If *Microcystis* caused the bloom, copper sulphate may be added at 25 kg/ha. While there are regulations in place to prevent the use of copper sulphate, it was sometimes used by the farmers.

3.3.2 Stocking and rearing

The fry are reared in the nursery ponds for 30 to 40 days. This rearing period was considered a cycle, and due to limited space, many farmers reported using the same pond for at least three to four cycles per season. Two types of nursery systems are used in Bangladesh, *viz*.

- Single stage nursing
- Two stage nursing

The single stage nursing system involves growing the fry to fingerlings in one operation. Stocking densities are maintained at 1.0 to 2.0 million spawn/ha, and the fry grow to 5 to 7 cm fingerlings within 4 to 6 weeks. The two stage nursing system involves the fry being reared for 10 to 15 days in nursery ponds at high densities (>2.0 million spawn/ha), followed by grading and stocking in other nursery ponds at densities of 0.2 to 0.3 million/ha. The fry are reared in the secondary ponds for a further 4 to 6 weeks.

In some cases all the three major carps (catla, rohu and mrigal) are reared in a single pond. However, some farmers reported the rearing of single species, or combinations of only two species. Catla is often reared separately while rohu and mrigal are mostly reared together, often with exotic carp species. The rationale for rearing catla separately appeared to be that many customers only wanted to buy catla, and thus rearing them separately made the harvesting and sales process easier. The choice of species cultured, their combination and density were found to vary between regions. Many species combinations were observed in the survey (Table 7).

TABLE 7
Eight examples of species combinations and stocking densities cultured in nursery ponds

	Name of fish species	Density (kg/ha)
1	Catla	5–12.5
2	Rohu	18.7–20
3	Mrigal	25
4	Catla : rohu : mrigal	3.75 : 7.5 : 3.75
5	Rohu : mrigal	5 : 15
6	Catla : rohu	1.25–2.5 : 5–6.25
7	Mrigal : silver carp	2.5 : 2.5
8	Rohu : mrigal : silver carp	12.5 : 6.25 : 6.25

Source: Field survey (2010).

Farmers in the Comilla region practiced both types of nursery production. They prepared their ponds following the procedures outlined above, and stocked three major carps together. Some farmers stocked 5 day old fry at high densities, and reduced the density after 15 to 20 days of culture. This was achieved by transferring the fry into other ponds. The nursery cycle was initiated using 15 to 20 day old fry (± 1.3 cm) of catla, rohu and mrigal at densities of 3 750–5 000, 32 500–37 500 and 16 250–17 500 fry/ha respectively.

3.3.3 Nursery feeding and rearing

Phytoplankton and zooplankton produced in the newly prepared nursery ponds were the primary source of live feed for four to five day old fry. In addition to the natural food, supplemental feed was provided on a regular basis. Farmers fed hard boiled chicken egg-yolk to the newly hatched spawn for the first two to three days. Three to four eggs were required for each kg of fry. Sometimes 0.5–1.0 kg of cooked and diluted wheat flour was mixed with the egg-yolk. Subsequently the fry were fed wheat flour (1.0 kg wheat flour/kg of fry) for three to four days. The wheat flour was mixed with water and broadcasted across the pond surface. When the fry were seven days old, mustard oil cake was provided at the rate of 2 kg feed/kg fry. Prior to feeding, it was soaked in water for at least 24 hours and further diluted with water before being broadcasted over the water surface (Figures 9 and 10). This feeding schedule was used for the next seven days. After two weeks, most of the farmers switched to mustard oil cake, and continued feeding the same ration until the fry were sold at 4–5 g, some 30 to 40 days after hatching. Some farmers added rice polish to the mustard oil cake when the fry were about 1.2 cm, and the fry could ingest small food particles.

FIGURE 9
Overnight soaked mustard oil cake in a pot (left) and mustard oil cake diluted with water (right)

COURTESY OF FAO/M.R.I. SARDER.

FIGURE 10
Broadcasting of overnight soaked and diluted mustard oil cake to a nursery pond

COURTESY OF FAO/M.R.I. SARDER.

In addition to farm-made supplemental feeds, commercially manufactured nursery feeds are used by some of the farmers. These are in powder form and are primarily designed for use with striped catfish, Nile tilapia (*Oreochromis niloticus*) or climbing perch (*Anabas testudineus*). Some respondents in the Comilla region reported using commercially manufactured feeds as first feeds, and subsequently changing to farm-made supplemental feeds. To improve the fry health, Megavit-Aqua (a vitamin-mineral and amino acid supplement) was reported being used at 1 g/kg of feed.

In general, during first 7 to 14 days of rearing the fry are fed to satiation. At the end of this period the fry reach 0.5 inches (1.27 cm), are placed in hapas, and the feed ration adjusted. The ration is based on the body weight of the fry. Between 14 and 21 days, the fry are fed at 60 percent of body weight per day. The ration is reduced to 40 percent between 21 to 30 days of rearing. At 2 to 3 g, the ration is reduced to 15 to 20 percent of body weight per day. At 15 to 20 days post hatch, the majority of the farmers reduce their stocking densities by splitting the groups between ponds. Decreasing the density results in faster growth rates. Prior to feeding, some farmers reported pulling horras across the pond bottoms. This was undertaken to stimulate the appetite of the fry and to release toxic gases from the pond sediments. Most of the farmers provided supplemental feeds between two and three times a day during the early rearing stages. During the latter production phase, feeding was reduced to two times a day - in the morning and in the evening. Though small fry require supplemental feeding every day, feeding was partially or completely ceased during heavy rains, on extremely hot days, on cloudy days, or in the presence of toxic gases that originate from the decomposition of uneaten feed. In the event that the pond water contained excessive levels of plankton, some farmers choose to stop supplemental feeding for at least a week.

Farmers rear the fry for a maximum of 30 to 40 days, and start to sell them from 30 days onwards, when they reach approximately 1 to 1.5 inches (~2.5–3.8 cm). In some cases the same pond was stocked for two to three nursery production cycles in succession. Between production cycles, phostoxin or rotenone was used to kill the remaining fish, and the pond was prepared for the next production cycle using lime and organic and inorganic fertilizers. Some farmers, who have grow-out ponds, rear the fry for seven to eight months in their own nurseries and stock them out into their ponds as juveniles (10 to 15 inches/25–38 cm; 70 to 100 g).

Farmers purchase their feed ingredients from nearby markets and transport them to their farms in vans or small vehicles. The distance between the markets and the farms is usually from 5 to 10 km, but may sometimes be a maximum of 20 km. Transport costs can be as high as US$30/tonne. The ingredients are kept in store rooms for at least

seven days, usually on cement or mud floors. When the feed is stored on mud floors a jute mat is placed underneath the feed to protect it. Feed and feed ingredients are also stored on a bamboo or wooden dais (platform). Despite taking these precautionary measures, cockroaches, mites, rats, and sometimes moisture damage the quality of the feed and the feed ingredients.

Most of the nursery farmers are not well-off and lease their ponds. Due to a lack of funding some farmers are unable to regularly feed their fry, and experience problems with maintaining water quality. The nursery activities are generally totally performed by the farmers. However sometimes they employ casual labourers and, in some instances, they over-feed or under-feed the fry. Taking into consideration of the costs of pond leasing, pond preparation, purchase of fry, labour and other related production activities, it was reported that farmers could make profits of between 20 to 50 percent on their investments.

While fry production is a vital component of the fish culture value chain, its importance is often ignored or overlooked. To date, there have been no government or privately funded programmes to improve nursery and fry production systems in Bangladesh. Importantly, the marginalised subsistence farmers that represent the major stakeholders in the sector are unable to develop initiatives to improve production. This is primarily due to a lack of funding, land, education and leadership.

The farmers provide supplemental feeds to their fry at regular intervals; however, the survival rate of newly stocked fry is often very low. The reason for this is difficult to ascertain, however an inadequate supply of nutrients could be an important factor. It was noted that during the latter stages of the production cycle, farmers only fed mustard oil cake as a supplemental feed. It is unlikely that the mustard oil cake would provide all the necessary nutrients required for optimal growth. As an alternative, mustard oil cake mixed with other fed ingredients such as wheat flour, rice polish, fishmeal and vitamin and mineral mixtures could be used. The use of industrially manufactured nursery feeds could also be considered. If industrially manufactured feeds prove to be too expensive, low-cost feeds could be produced for the farmers in the local feed mills. The quality of mustard oil cake is another important issue; if the oil cake is adulterated or inappropriately stored, it can degrade, and the toxins produced can result in mass mortalities. To preserve the quality, mustard oil cake should be kept on cement floors or on wooden platforms in store rooms.

3.4 Indian major carps grow-out systems

Indian major carp aquaculture is primarily undertaken in pond and to some extent in oxbow lake culture systems. The total area of ponds and oxbow lakes in Bangladesh is 310 513 ha. In 2008, production in these systems was approximately 870 827 tonnes, contributing 33.9 percent to the total national fish production (DoF, 2009). There are two grow-out systems that are used for Indian major carp production in Bangladesh, *viz*.

- Improved-extensive culture in oxbow lakes
- Semi-intensive culture in ponds.

The semi-intensive culture systems are the most commonly used and require feeds to supplement the natural productivity of the ponds (Barman and Karim, 2007). The promotion of semi-intensive polyculture systems has significantly enhanced the production of communal ponds where the water is used for various purposes, particularly in rural areas of Bangladesh (ADB, 2005).

3.4.1 Pond preparation

Pond preparation for grow-out systems were found to be similar to those procedures that are used for broodstock pond preparation, the only difference being the selection of organic manures and inorganic fertilizers. Grow-out ponds were prepared using lime followed by organic (e.g. cow dung) manures and inorganic (urea, TSP, MP) fertilizers.

Most of the farmers showed a preference for cow dung as an organic manure. However some used poultry litter as an alternative at 250 to 1 000 kg/ha. If poultry litter was used to supplement cow dung, the dose of poultry manure was reduced to 250 to 500 kg/ha. In Rajshahi region, where cow dung was sometimes unavailable, the farmers used poultry litter as an alternative. In contrast, some farmers preferred to apply mustard oil cake at 125 to 250 kg/ha. The practice of applying mustard oil cake in this manner increased pond productivity. With respect to the use of inorganic fertilizers, urea, TSP and MP were commonly used. Zeolite and gypsum were reportedly used at 25 kg/ha and 100 kg/ha respectively. The use of organic manures and inorganic fertilizers was deemed essential during pond preparation. Additional fertilizer was sometimes applied at lower doses during the production cycle. The additional fertilizer was used to maintain the natural productivity of the ponds, and was usually applied at 15 or 30 day intervals. Some farmers applied composted manure produced from organic manures and inorganic fertilizers.

In Comilla region, farmers prepared their ponds using the organic and inorganic fertilizers described above; however in contrast to other regions, they also reported using cow dung at higher doses (2 000 to 3 000 kg/ha). No farmer in this region reported using poultry litter. In Comilla, the farmers believed that the poultry litter could introduce disease into the ponds, for example, Argulus infestations. All the respondents reported using fertilizers at 15 to 30 days intervals throughout the production cycle. Some farmers applied cow dung daily by mixing it with water, and then broadcasting the mixture over the pond water at 40 kg/ha. The farmers checked the abundance of plankton in the pond water almost daily. This was achieved using Secchi discs, visual observation, or by hand depth measurement and the use of white coloured aluminium plates. This practice was not commonly found in other parts of the country.

3.4.2 Species selection and stocking

The grow-out ponds used in Indian major carp culture varied in size. The smallest was reported to be 0.12 ha and the largest was 7.92 ha. Catla, rohu and mrigal, in combination with other indigenous and exotic carps, were stocked. While farmers in the various regions stocked indigenous and exotic fish in different combinations, it was catla, rohu and mrigal that were most commonly stocked together, thus representing the prime culture species. Amongst the exotic fish used, silver carp, grass carp, mirror carp (*Cyprinus carpio*) and silver barb were the most common; however, striped catfish and common carp (*Cyprinus carpio*) were also found in many combinations. Some indigenous carps for example, the kalbasu, kuria labeo, bata (*Labeo bata*) and even stinging catfish (*Heteropneustes fossilis*) and Asian catfish (*Clarias batrachus*) were also included in a few combinations.

The survey showed that at least 18 fish species including indigenous and exotic species were being cultured in various species combinations across different regions of the country, comprising a minimum of four and a maximum of ten species. Among the species, catla, rohu, mrigal, silver and grass carp were the top ranking species followed by common carp, mirror carp, Nile tilapia and silver barb. The percentages of occurrence of most common fish species cultured in these systems were given in Figure 2. Farmers used combinations of species that optimised feeding behaviour and stocking densities. The choice of species varied markedly and was designed to avoid combinations that would result in inter-specific competition. While some species were reported in all the species combinations, others were reported in just 5.5 percent (Figure 3). Examples of the various species combinations that were observed are presented in Table 8.

TABLE 8
Indicative species combinations used in polyculture systems from different regions of the country

Combination 1	Combination 2	Combination 3	Combination 4	Combination 5
Catla, rohu, mrigal, silver carp, grass carp, mirror carp, bighead carp, striped catfish	Catla, rohu, mrigal, silver carp, grass carp, mirror carp, silver barb	Climbing perch, striped catfish, catla, rohu, silver carp	Catla, rohu, mrigal, silver carp, grass carp, mirror carp, silver barb, Nile tilapia, black carp, bata	Catla, rohu, mrigal, silver carp, grass carp, silver barb, orangefin labeo/kalbasu, kuria labeo, common carp

Source: Field survey (2010).

3.4.3 Feed preparation and feeding in the grow-out systems

In addition to using the natural productivity of the ponds as feed, most farmers made use of farm-made feeds. A high degree of variability was found in the ingredients and feed formulations used, and their application rates. Table 9 presents the levels of common ingredients commonly used in farm-made feeds.

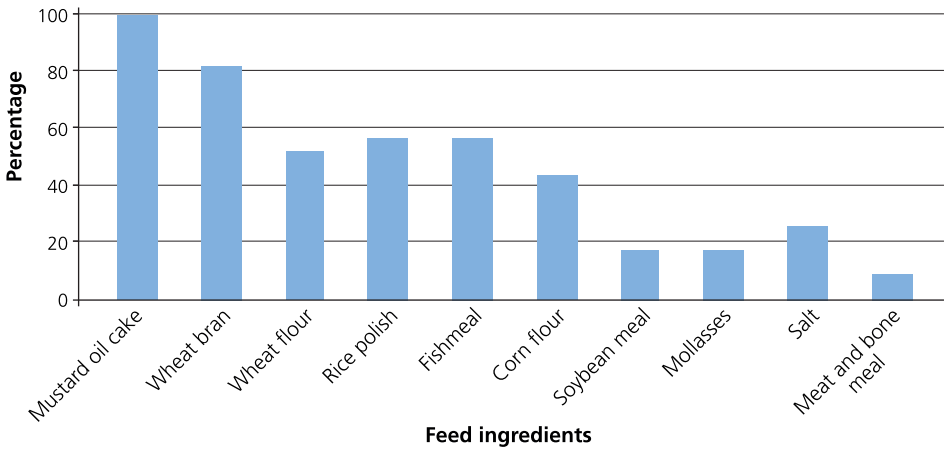
TABLE 9
Levels of commonly used feed ingredients in farm-made feeds

Ingredient	Indicative inclusion rates (%)
Mustard oil cake	15–30
Wheat flour	5–15
Wheat bran	10–30
Rice bran/polish	25–50
Fishmeal	5–10
Corn flour	5–10
Molasses	1–2

Source: Field survey (2010).

The variability in the feed ingredients used was dependent on their regional availability. For example, while the use of corn flour dominated in Jessore region, soybean meal was used more extensively in Comilla region. Figure 11 shows the occurrence of feed ingredients used in the manufacture of farm-made feeds.

FIGURE 11
Occurrence of feed ingredients used in farm-made feed formulations



Source: Field survey (2010).

In addition to these ingredients, some farmers used vitamin premixes (0.5 percent), minerals (one percent) and soybean oil (one percent) in their formulations. As a result of financial constraints, some of the poorer farmers were only able to afford to use mustard oil cake and rice polish or wheat bran. These they mixed at equal ratios and used as supplemental feeds.

Farmers primarily depend on mustard oil cake as the major plant protein source in their formulations. The survey revealed that all the farmers used mustard oil cake, and that it was readily available throughout the country. Sometimes soybean meal or linseed oil cake was used as a supplement to mustard oil cake. Fishmeal was considered as the main animal protein source, and the commercial farmers used it in their formulations. Marginal and poor farmers were unable to use it on a regular basis due to availability and cost issues. Fishmeal is primarily produced in Bangladesh using trash fish and by-catch species; however production is insufficient to meet the demand. The Bangladesh Fisheries Development Corporation (BFDC) produces fishmeal at its four fishmeal production plants. The Corporation has a total production capacity of eight tonnes/day (Murtuza, 1998). To satisfy the demand, fishmeal is imported from other countries, e.g. China, Malaysia, and the United States of America. In addition, meat and bone meal is imported from Denmark, Belgium, and Croatia. The protein content of these feed ingredients ranges from 40 to 55 percent (Barman and Karim, 2007).

Farmers in the Jessore, Rajshahi and Mymensingh regions showed a preference for farm-made feeds because they were relatively cheap (US$260 to US$315 per tonne), of a high quality, and easy to prepare. However, some regional variability was found in the preparation and administration of these feeds. The feed preparation techniques that were reported included:

- The mustard oil cake was placed in a plastic or cement bowl and soaked in water for at least 24 hours. The other ingredients were added to the soaked mustard oil cake. The material in the bowl was mixed homogenously by hand until a dough was formed. Between 09.00 and 10.00 hours, the dough was fed to the fish at different locations in the pond. Some farmers fed twice a day, and in these cases the daily ration was divided into two parts; one part was given to fish at between 09.00 to 10.00 hours, and the remainder between 16.00 to 17.00 hours.
- All feed ingredients were measured and placed in an earthen bowl. Water was added and the ingredients mixed homogenously. The earthen bowl was then dipped into the water in a corner of the pond. In large ponds, the feeds were presented to the fish at a number of locations around the pond. As the feed contained a high water content, some feed materials were lost during ingestion.
- On large farms (60 to 250 tonnes/year) the dry feed ingredients were mixed homogeneously. The mixtures were placed in plastic or jute bags (25 to 50 kg in each bag) and held in a store room. When required, the feed materials were placed in plastic or earthen bowls, and water was added. After two to three hours of soaking, the feed materials were once more mixed and kneaded into a dough. The dough was fed to the fish at different locations around the pond. Feeding was undertaken in the morning, and if necessary in the afternoon.
- Pelleted feeds were manufactured at local feed mills. To obtain the feed ingredients, the farmers could either purchase them from local markets and deliver them to the mill; or alternatively, the mill owner would provide the necessary ingredients from their stock. The miller produced the pellets using the supplied ingredients. To manufacture them, the ingredients were mixed and water added. The moist feed mixture was extruded into pellets (3 to 4 mm). The pellets were sun dried for five to six hours, and placed in plastic bags for storage (as shown in Figures 12, 13, 14 and 15). The pelleted feed was broadcast at two to three percent of body weight per day.

The survey revealed that 23 percent of the famers used commercially manufactured aquafeeds to supplement their farm-made feeds – this practice was most common in Comilla region. The feeds contained protein contents ranging from 25 to 30 percent. (Food conversion ratios (FCR) were 1.3:1 to 2:1. Farmers fed by broadcast feeding twice a day at 09.00 to 10.00 hours and 16.00 to 17.00 hours. The fish were fed at three to four percent of body weight per day. The commercial feeds were comparatively expensive, ranging between US$362 and 435/tonne. In contrast, the cost of the farm-made feeds was US$260 to 315/tonne (Table 10). At times, the high price of the commercially manufactured aquafeeds made them unaffordable to the marginal and poor farmers. The proximate composition of selected commercially manufactured aquafeeds is presented in Table 11.

TABLE 10
Prices of selected commercially manufactured aquafeeds and farm-made feeds

Commercial feed	Price (US$/tonne)
Quality carp feed	377
Mega feed	435
Aman feed	405
SB super feed	405
Aftab carp feed	377
Madina fish feed	362
Teer fish feed	391
Farm-made feeds	
Various formulations	260–315

Source: Field survey (2010).

TABLE 11
Proximate composition of selected commercially manufactured aquafeeds used in grow-out systems

Ingredients	Dry matter (%)	Crude protein (%)	Crude lipid (%)	Crude fibre (%)	Ash (%)	NFE (%)
CP pangas feed	88.9	31.9	6.6	7.6	14.5	39.4
Quality carp feed	92.5	28.4	6.6	8.4	16.8	38.8
Mega feed	90.3	29.3	4.2	9.0	12.2	45.3
Aman feed	90.3	25.6	7.8	8.7	22.9	35.0
SB super feed	91.1	26.4	8.6	7.9	14.7	42.4
Aftab carp feed	89.2	24.5	6.1	8.7	15.6	45.1
Madina fish feed	90.9	25.6	7.6	10.6	18.9	37.3
Teer fish feed	89.3	26.9	7.9	8.5	16.4	40.3

NFE = Nitrogen free extracts.
Source: Field survey (2010).

All farmers in every region reported using either farm-made feeds or commercially manufactured feeds. In terms of their efficacy, the farmers do not record FCR, and thus it is difficult to establish whether the feeds were well formulated or were being applied effectively.

Fish were reared in the ponds for an 8 to 12 month period, and subsequently harvested and sold (Table 12). The production varied across the regions and ranged from 750 to 15 000 kg/ha. The production costs varied from region to region as the cost of labour, the leasing of the ponds, and even the feed ingredients costs differed. For example, the costs of leasing ponds varied from US$218 to 4 348/ha/year. While the farmers sold their fish either directly to their customers or to the middle men in the fish market, fish prices varied between locations. The majority of farmers spent a large portion of their investment on supplemental feeds; however, none of them could provide detailed levels of expenditure. It was clear that many farmers do not maintain production cost and income records. Therefore, it was not possible to determine production costs and net incomes. However, from the survey it was estimated that farmers made in the region of 40 percent profit on their initial investments.

The majority of the farmers reported feeding the major carps irregularly and with nutritionally incomplete diets. This was a result of their poor understanding of the nutritional requirements of the fish. In this regard, training on the dietary requirements of fish needs to be provided through the development of suitable workshops and extension materials e.g. leaflets, booklets, manuals etc. The training materials should include information that describes the selection of appropriate feed ingredients, storage, feed preparation and pellet manufacture, the calculation of FCR, record keeping, and the determination of the cost benefit ratios associated with feed use.

4. A CASE STUDY OF AN ADVANCED GROW-OUT FARMER

A case study was undertaken of a fish farmer from Char Fashion village, Mymensingh district. Mr Akand operated a hatchery and grow-out facility, and a feed mill to produce his own feeds as well as feeds for sale. The necessary feed ingredients were stored at the mill, and these were offered to local farmers who required assistance in the preparation of their supplemental feeds. Mr Akand had a good knowledge of fish culture techniques and had received training on various aspects of fish culture from the Department of Fisheries. He had a good understanding of pond preparation techniques, the selection of culture species, density effects, and supplemental feeding practices.

The fish farm comprised four ponds with a total area of 1.7 ha. The largest pond was 0.81 ha, and the smallest 0.3 ha. Prior to stocking, the ponds were fertilized with cow dung and poultry litter, applied at 1 250 to 2 500 kg/ha and 250 kg/ha respectively. Lime was added at 250 kg/ha. TSP and urea were applied at 50 to 62.5 kg/ha and 50 kg/ha respectively. In those ponds that have a clay substrate, MP was applied at 12.5 to 25 kg/ha. In addition, organic and inorganic fertilizers were applied at 15 day intervals throughout the production cycle to maintain the natural pond productivity. The species combination and the stocking density of fish are presented in Table 13.

The feed derived from natural pond productivity was regularly supplemented with farm-made feeds prepared using locally available ingredients (Table 14).

To prepare the feeds, the ingredients were placed on a cement floor and mixed homogenously. Approximately ten litres of water were added to 100 kg of dry feed mixture. The semi-wet mixture was placed in the pellet machine and extruded. The size of the pellet was regulated using dyes. Normally, 3 to 4 mm diameter pellets were produced (Figures 12, 13, 14 and 15). After sun drying for six hours, the pellet feed was placed in plastic or jute bags, and stored for up to 60 days. While the proximate composition of the feed was not established, the protein content was assumed to be approximately 25 percent. The feed cost was US$290 per tonne.

TABLE 12
Indian major carp production cycle, feeding schedules, and fertilizer use

Month	Type and size of fish at stocking[1] and at harvest (month 9)							Feeding schedules			Type of fertilizer	
	Catla (g)	Rohu (g)	Mrigal (g)	Silver carp (g)	Grass carp (g)	Common carp (g)	Silver barb (g)	Feed type	Feeding frequency (times/day)	Feeding rate (% BW[2]/day)	Organic cow dung (kg/ha)[3]	Inorganic TSP/urea (kg/ha)[3]
1	150–500 g	50–250 g	50–250 g	25–250 g	25–250 g	50–100 g	10–15 g	Farm-made dough/pellets	1–2	2–3	250–1 250	250–1 250
2								Industrial Pellets	1–2	2–3	as above	as above
3									as above	as above	as above	as above
4									as above	as above	as above	as above
5									as above	as above	as above	as above
6									as above	as above	as above	as above
7									as above	as above	as above	as above
8									as above	as above	as above	as above
9 Harvest	1.5–3.0 kg	0.75–1.5 kg	0.75–1.5 kg	1.5–3.0 kg	1.5–2.5 kg	1.0–2.0 kg	0.25–0.4 kg					

[1] Farmers stock variable sizes and stocking densities; [2]BW = body weight; [3] applied at 15–30 day intervals.
Source: Field survey (2010).

TABLE 13
Stocking characteristics of the major aquaculture species in the case study

Species	Density (number/ha)	Age of fish at stocking	Weight of fish (g) at stocking
Catla	250	1 year	200–250
Rohu	1 250	1 year	150–200
Mrigal	1 250	1 year	150–200
Silver carp	1 750–250	1 year	150–200
Grass carp	250–500	1 year	150–200
Silver barb	1 250	1 year	50–100
Nile tilapia (mono-sex)	50 000	40–45 days	10–15
Orangefin labeo/kalbasu	750	1 year	150–200
Common carp	500	1 year	150–200
Mirror carp	250	1 year	150–200

Source: Field survey (2010).

TABLE 14
Ingredients and dietary formulation used in farm-made feed used in the case study

Feed ingredient	% inclusion rate
Mustard oil cake	20
Rice polish	50
Wheat bran	4
Fishmeal	10
Corn flour	15
Nutrimix (vitamin mixture)	0.5
Mega binder (pellet binder-made in China)	0.5

Source: Field survey (2010).

The feed was fed to the fish at three to four percent of body weight per day. The ration was divided into two parts that were fed at 10.00 and 16.00 hours. The feed was normally broadcast, and was usually consumed by the fish within 10 to 20 minutes of application. To adjust the feed ration, the fish were sampled once a month and their weight and length were measured. The health and the presence of parasitic infestations were also noted at this time. Though the feed was supplied regularly, the fish were not fed supplemental feed for one day in every two weeks. This practice was established to ensure that the fish maintained good appetites. Feeding was stopped during adverse environmental conditions – very hot, humid or rainy days. Supplemental feeding was also discouraged when gas bubbles appeared in the ponds; these bubbles (hydrogen sulphide) indicated overfeeding in the pond and the decomposition of uneaten feed.

The fish were reared for at least six to seven months before being sold. Catla, rohu, mrigal, silver carp, grass carp, common carp and kalbasu were sold at a size of 2 kg, 500 to 600 g, 700 to 1 000 g, 1 to 1.5 kg, 3 to 4 kg, 1 to 2 kg, and 500 to 700 g respectively. Tilapia was sold at 250 to 300 g. It was established that production in those ponds (excluding Nile tilapia) was about 6 250 to 7 500 kg/ha, but this increased from 17 500

to 20 000 kg/ha when Nile tilapia was introduced. The average market price of the fish was US$ 1 884/tonne. Recently, production costs have increased, and these now represent between 50 to 60 percent of total investment costs. The production cost includes the cost for leasing ponds (US$600 to 4 348/ha/year), fish, feed, fertilizers, and labour (at least two labourers with a monthly salary of US$72 to US$87). There was no accurate calculation of the total income generated by the farmer; however it was assumed that he makes in the region of 40 percent on his investment.

FIGURE 12
Soaking of feed ingredients with water (left) and mixing of feed ingredients in a bowl (right)

COURTESY OF FAO/M.R.I. SARDER.

5. RECOMMENDATIONS

Aquaculture, and especially carp culture has expanded throughout Bangladesh, and the sector now contributes significantly to the total national fish production. However, the production of carp is being hampered by the use of poor quality feeds and their on-farm management. To ensure the long term sustainability of the sector, it is important to identify the problems associated with feed and feed management practices, and to provide solutions. In this regard, the following recommendations are made to promote sustainable aquaculture development:

- The continued expansion of the sector requires the provision of appropriate supplemental feeds. As most of the marginal and poor rural farmers have no knowledge of fish nutrition, information outlining their nutritional requirements, feed formulation, feed quality, management and feeding protocols needs to be provided through extension services and training programmes.
- Farmers should be made aware that the primary productivity of their ponds impacts production. Information describing methods of increasing phytoplankton, zooplankton, benthos and periphyton production through organic and inorganic fertilization should be provided. Farmers need to be

FIGURE 13
Mixed feed ingredients placed in the pellet machine (left), pellet dyes of different sizes (middle) and pellet production (right)

COURTESY OF FAO/M.R.I. SARDER.

FIGURE 14
Extruded pellets in the basket (left) and their sun drying (right)

COURTESY OF FAO/M.R.I. SARDER.

FIGURE 15
Dried pellets are being packed (left) and stored (right)

COURTESY OF FAO/M.R.I. SARDER.

aware of the implications of using farm-made feeds, and their potential impact on pond water quality.

- Feed ingredients, and especially those that are used by other farming systems, e.g. the poultry and livestock feed industry, should be made available to the fish farmers at cost effective prices. In this regard, government could consider distributing the ingredients through registered distributors or dealers, and could consider providing subsidies to the farmers.
- Since the locally manufactured pelleted feeds are more effective than the farm-made feeds, farmers should be encouraged to use pelleted feeds. To make the pellets, small scale local feed mills need to be established. The government should provide the necessary support to establish such mills. The feed millers would require training to ensure the quality of the feed produced.
- Feed storage and maintaining feed quality prior to use is an important issue. Feed and feed ingredients should be stored on cement floors underneath a jute mat, or on a wooden platform. In those instances where the store room has a mud floor, the feed should be stored on wooden or bamboo platforms. In addition, the store rooms should be well ventilated.
- Although a number of dedicated aquafeed manufacturers have established operations in the country, the quality of many of the feeds that are produced remains questionable. It is often reported that the feed manufacturers use low quality feed ingredients, and add hormones and growth promoters to the formulation. These supplements may result in adverse effects not only to the environment, but also to human health. The Department of Fisheries needs to take appropriate steps to stop these practices. This could be achieved through the implementation of the Fish and Animal Feed Act.
- Fishmeal is an essential component of fish feeds, and at present there is a shortage in the domestic supplies that are available to the sector. The government should take the necessary measures to encourage fishmeal production in the country. If necessary, quality fishmeal should be imported from abroad.
- Farmers are not monitoring their feed use or using FCR to determine feed efficiencies. It is important to encourage farmers to maintain appropriate feed records, calculate FCR and, where necessary, take corrective actions. This could be achieved through the provision of extension services and training programmes.
- Farmers in all the three production categories, and especially in the nursery and grow-out systems, sometimes fail to take appropriate care of their fish, and use supplemental feeds inappropriately. This is primarily a result of their financial situation and a lack of funds to purchase the feeds. Financial support to purchase feeds should be provided by the government or private banks.
- The linkages between government, University laboratories and research institutes needs to be strengthened, and technical support provided to the aquafeed industries, feed millers and, in some cases the fish farmers, to analyze their feed and feed ingredients.

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ANNEX

Unofficial translation of salient features of Fish and Animal Feed Act (Act 2 of 2010)[2]

(i) Government i.e. the Ministry of Fisheries and Livestock will fix the standard quality of feed and feed ingredients, and it will be obligatory for the feed mills and industry to maintain the standards.

(ii) Upon examination in a quality control laboratory, any feed mill or industry that fails to maintain the said quality of feed and feed ingredients may be closed by the regulatory authority and have its licence cancelled.

(iii) To verify the quality of marketed feed, the Director General of the Department of Fisheries or his nominee can take feed samples from any industries, mills, exporter or dealer at any time and check the quality of the feed.

(iv) If the feed is found to be adulterated or unsuitable for fish, the whole consignment of feed will be confiscated and the activities of feed miller, exporter or dealer will be considered as a criminal offence.

(v) No person or company may directly or indirectly produce, import or market any harmful or adulterated fish, or any animal feeds that contain toxic or harmful substances to humans, fish, animals or the environment.

(vi) Feed will not be allowed to be sold unless it is packaged and labelled with the manufacturers' name or country of origin, address and registration number, production and expiry dates, weight, nutritional information and its ingredient composition.

[2] Approved by the Government of Bangladesh on 28 January 2010.

On-farm feed management practices for striped catfish *(Pangasianodon hypophthalmus)* in Mekong River Delta, Viet Nam

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ABSTRACT

The Mekong delta is considered as the most important region for aquaculture production in Viet Nam and in 2008 accounted for approximately 73 percent of the total national aquaculture production (IFEP, 2009). The delta has a total freshwater area of 641 350 ha, of which 480 181 ha has the potential for further aquaculture development; and has the most diversified aquatic farming activities and greatest potential for increasing aquaculture production. There are several species that are commercially produced in the delta, of which striped (or tra) catfish is the most important. The production of striped catfish reached 1 147 000 tonnes in 2009 (Fisheries Directorate, 2010).

The rapid expansion of striped catfish farming has resulted from various factors, of which the improvement of feed and feeding practices has played a key role. The feed and feeding of striped catfish has changed overtime. In the early days of the striped catfish farming industry, farm-made feed (FMF) was mainly used. FMF was used across all the culture systems including cages, pens and ponds. Manufactured pelleted feed (MPF) was first introduced to striped catfish cultured in cages in 1995 and 1996. Since 2004, the use of MPF has gradually been accepted by striped catfish farmers. The survey indicated that 63.3 percent, 17.4 percent and 19.3 percent farms used MPF, FMF or a combination of MPF and FMF, respectively. Over the past five years, the striped catfish MPF industry has been developing rapidly in Viet Nam, with annual production increasing from 300 000 tonnes in 2004 (Tran, 2005) to 2 240 000 tonnes in 2008 (Annex 1).

The feeding practices used to culture striped catfish depends on the stock size and feed types. The feeding rates of MPF vary between 2 to 5 percent of body weight per day depending on the body weight of the fish, while the feeding rates for FMF are about 1–2 percent higher. Normally, three feedings are applied per day for the stock size of less than 100 g, one daily feeding is applied for the stock size of 800 g to harvest, and two daily feedings are used between these sizes. The feed conversion ratios vary according to feed type, and range from 1.6:1 for MPF to 2.9:1 for FMF. Feed cost accounts for the largest portion of

the total production cost. The feed cost of striped catfish fed full MPF, full FMF and combined MPF and FMF covers 82.9, 77.4 and 79.0 percent of the total production costs, respectively. The profit of striped catfish farming depends greatly on the feed cost and the farm-gate price. The survey showed that over the survey period 55 percent of farms lost money.

There are several issues related to the management of feed in striped catfish culture that require further research. These relate to the determination of the nutritional requirements of the larger stock sizes, on-farm feed digestibility studies, the development of feed management strategies, and the use of FMF.

1. INTRODUCTION

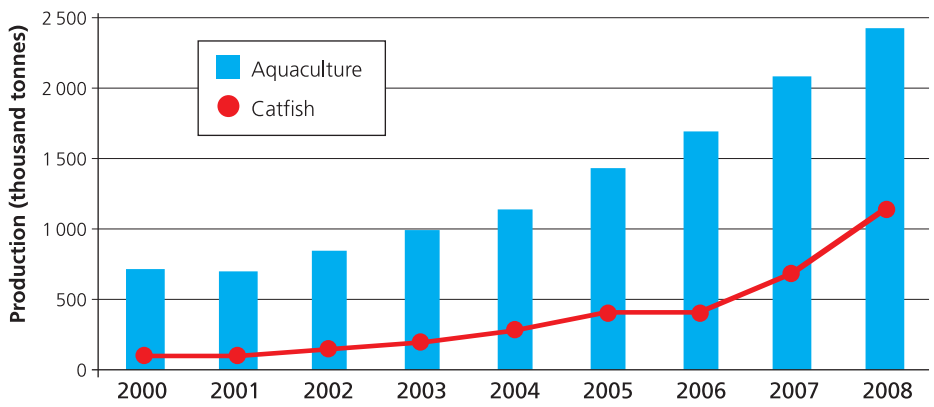
1.1 Rationale

Viet Nam has a high potential for aquaculture development due to its natural endowment of ponds, rice fields, rivers, lakes, estuaries and coastal areas. The Vietnamese Government estimates that the total area of water that may be used for aquaculture is 1.6 million hectares (Ministry of Fisheries, 2003). The aquaculture sector was initiated in the early 1960s with small-scale extensive culture systems, and during the past two decades there has been rapid growth in this sector. This expansion has been as a direct result of a diversification in farming practices, and the production of exportable species at increased levels of intensification (Nguyen and Dang, 2009).

In 2010, Viet Nam became the third largest aquaculture producers in the world (FAO, 2012). The Mekong Delta in the southern part of the country has a potential area for aquaculture development of nearly 1 370 000 ha, with 480 181 and 886 249 ha of freshwater and brackish and marine waters, respectively (IFEP, 2009). The delta has diversified aquatic farming activities and has the greatest potential of any area in the country for increasing aquaculture production.

There are several species that have been commercially produced in the delta, of which striped catfish (*Pangasianodon hypophthalmus*) predominates. In 2008, the total production of striped catfish represented 72.9 percent of the total aquaculture production in the delta (IFEP, 2009). In 2008, the production of striped catfish was 1 147 000 tonnes, and accounted for 47.1 percent of the total aquaculture production of Viet Nam (Figure 1). Catfish farming started at the beginning of the 1960s, and at that time included Mekong catfish (*Pangasius bocourti*), locally referred to *basa* and cultured in small cages, and striped catfish (*Pangasianodon hypophthalmus*), locally referred to *tra* and cultured mostly in small ponds. Striped catfish is a single species of

FIGURE 1
Striped catfish production in comparison with the total aquaculture production of Viet Nam

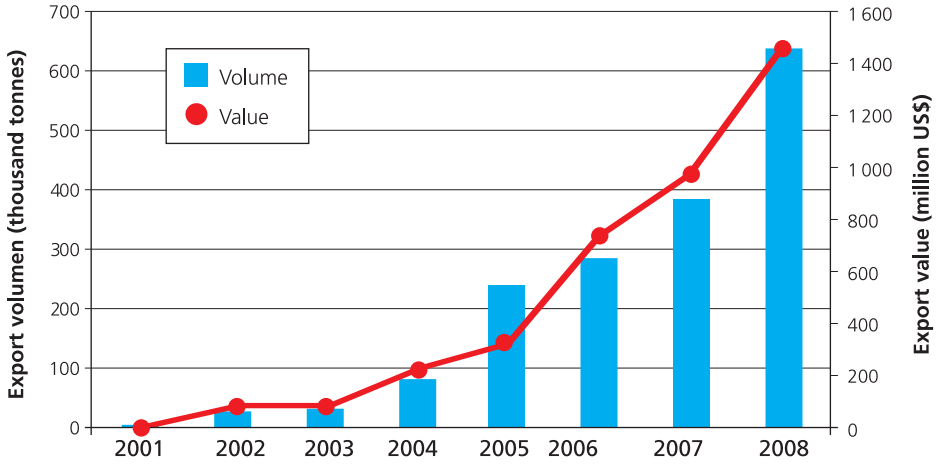


Source: IFEP (2009).

the genus *Pangasianodon* that occurs in the Lower Mekong Basin waters of Viet Nam, Cambodia, Lao People's Democratic Republic and Thailand. The fish has been farmed in the Mekong River Delta for decades as a home-based activity, primarily providing the fish needs of rural households. In recent years, commercial striped catfish farming has been based on cage, pen and pond based systems. However, since 2004, cage and pen culture have gradually reduced, and are now of no importance in the striped catfish production sector. Since 2006, catfish farming in the Mekong River Delta comprised of 95–97 percent striped catfish and 2–3 percent Mekong river catfish (Nguyen and Dang, 2009).

Over the past decade, striped catfish has become the biggest aquaculture export commodity in Viet Nam; recently export volume has increased significantly (Figure 2). The markets for striped catfish have expanded from the United State of America alone at the beginning of the 1990s to 125 countries and territories in 2008. In 2008, European markets accounted for 44.7 percent of Vietnamese production, the Russian market a further 12.6 percent, and the US market 3.7 percent (Nguyen, 2008).

FIGURE 2
Striped catfish export growth



Source: Nguyen (2008) and IFEP (2009).

1.2 Objectives of the study

The general objectives of this study were to assess the feed and feed management practices for striped catfish pond culture in the Mekong river delta. The specific objectives were to describe the changes in farming practices, the current feed use and feed management practices for broodstock, nursery and grow-out stages, the research needs, and the regulatory frameworks that apply to feed and feed management.

2. RESEARCH METHODOLOGY

2.1 Selection of study locations

The case study focused on striped catfish nursery and grow-out in ponds. Pond culture is the predominant production system in the Mekong river delta. Six representative locations (districts) of striped catfish farming in the Mekong river delta were selected for the study (Figure 3). Farmers from 112 grow-out and 30 nursery farms from the six selected districts were randomly interviewed (Table 1). Among the selected grow-out farms, 16 percent had total pond areas greater than 1.5 ha, and 84 percent of farms were less than 1.5 ha, which was considered as small scale. These farms were operated by individual farmers.

FIGURE 3
Map of the Mekong River Delta, with blue circles indicating the areas of striped catfish farming and yellow circles showing the survey locations

Source: Adapted from Nguyen *et al.* (2004).

2.2 Data collection and analysis

Semi-structural questionnaires were used to obtain technical and financial data from the farm owners or farm managers. The data on striped catfish growth in ponds were recorded from 14 grow-out ponds and based on 2009 and 2010 data.

Three types of grow-out feeding practices were categorized in this survey. These comprised the feeding of manufactured pelleted feed (MPF), the feeding of farm-made feed (FMF), and a combination of feeding MPF and FMF. Feeding of MPF refers to feeding striped catfish for the entire production cycle using industrially produced floating pellets, and using different sized pellets and feed formulations based on the size of the fish. The feeding of farm-made feed (FMF) refers to feeding striped catfish for the entire production cycle on feeds that are prepared at the farm site using locally available ingredients. A combination of manufactured and farm-made feeds refers to feeding striped catfish with MPF for the first two and the last 1.5 to 2 months of the production cycle, and feeding FMF for the intermediate 4 to 4.5 months during the middle of the culture cycle.

The collected data were collated and where appropriate mean, standard deviation and simple regression analyses were undertaken.

TABLE 1
Number and ratio of respondents by study locations

Study locations (district or town names)	Grow-out farms		Nursery farms
	Total of respondents	Ratio (%)	
Binh Thuy	6	5.36	
O Mon	20	17.9	12
Thot Not	36	32.1	10
Long Xuyen	20	17.9	8
Cu lao Dung	15	13.4	
Tieu Can	15	13.4	
Total	**112**	**100**	**30**
- Farms that used manufactured pelleted feed (MPF)	69	61.6	
- Farms that used farm-made feed (FMF)	19	17.0	
- Farms that used combined MPF and FMF	21	18.8	

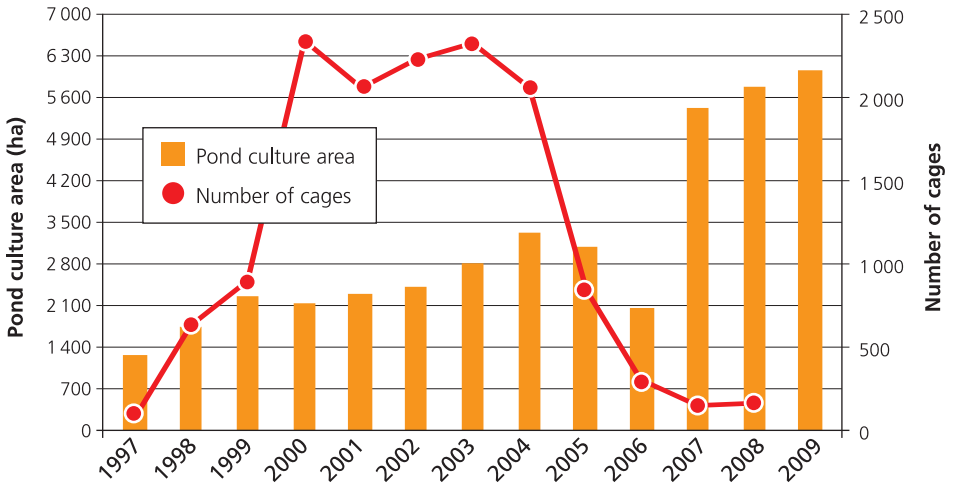
3. RESULTS AND DISCUSSION

3.1 Changes in striped catfish farming practices

The historical trends in the catfish farming sector in the Mekong Delta have been dealt with in detail by Nguyen and Dang (2009). Briefly, the intensive culture of striped catfish in ponds started in 1981–1982 by a famer in Can Tho city using wild caught fingerings and farm-made feeds. The success of striped catfish culture in ponds, together with the availability of hatchery-reared fingerlings, stimulated the development of striped catfish production in cages and pens. Since 2004, striped catfish farming has primarily become a pond culture activity (Figure 4), and the reasons for this change have been reviewed elsewhere (Nguyen and Dang, 2009; Phan *et al.*, 2009). The decline of cage and pen culture practices were primarily attributed to slower growth rates, higher mortality rates, and frequent disease outbreaks that led to reduced financial efficiencies compared to pond culture systems (Nguyen *et al.*, 2004; Nguyen and Dang, 2009). In recent years, the pond culture sector has increased in term of the area under culture, reaching over 5 700 ha of ponds in 2008 (Figure 4). While pond culture systems are operated at different scales, all are operated at a high level of intensification (Nguyen and Dang, 2009).

There were 1 174 striped catfish farms in operation in the six selected districts at the time of survey. The farms were categorized as <1.5 ha (82.7 percent), 1.5–5 ha (14.7 percent), 5–10 ha (1.87 percent) and >10 ha (0.77 percent). Most were operated as individual farming units, the exception being the 2.64 percent of farms that were operated by companies. According to Phan *et al.* (2009), the size of striped catfish farms in the Mekong delta was categorized as 72 percent <5 ha and only 9 percent being 10 ha; the average farm size was recorded at 4.09 ha.

FIGURE 4
Change in striped catfish production systems



Source: Nguyen (2008) and IFEP (2009).

3.2 General technical information of striped catfish farming

Technical information describing striped catfish culture in ponds is presented in Table 2. Pond sizes are generally small and vary between 0.30 and 0.33 ha; however, pond depths are high and vary between 4.28 to 4.61 m. The type of feed that was applied was not affected by the size of ponds that were used. These figures generally agree with the findings of Nguyen and Dang (2009), who reported catfish pond sizes between 0.4 to 0.42 ha, and Phan *et al.* (2009), who reported striped catfish pond depths ranging between 2.0 to 6.0 m with the great majority of farms (69 percent) using pond water depths of 3.5 to 4.5 m. These ponds are deeper than those that are used to farm other species in Asia.

TABLE 2
General technical information of striped/*tra* catfish farming in grow-out stage

Technical information	Categories			
	Overall (n=91)**	MPF (n=59)	FMF (n=15)	MPF+FMF (n=20)
Pond area (ha)	0.32±0.19	0.33±0.20	0.30±0.16	0.33±0.21
Pond depth (m)	4.39±0.88	4.28± 0.98	4.46± 0.7	4.61±0.57
Water depth (m)	3.64±0.75	3.46±0.80	3.83±0.54	3.94±0.55
Stocking density (fish/ha)	48.2±24.0	47.6±24.6a	50.3±28.9a	47.3±19.8a
Survival rate (%)	74.2±17.7	73.0±16.5a	77.3±23.8a	74.2±16.7a
Culture period (months)*	8.63±2.66	8.17±2.2	9.16±2.97	9.05±3.32
Productivity (tonnes/ha/crop)	360±162	325±153a	398±137ab	439±188b

Notes: Numbers represent mean ± standard deviation; * including nursery period; ** n: number of respondents; values in the same row with same superscript are not significantly different (p<0.05) (t-test).
Source: Field survey (2010).

Irrespective of feed type, the stocking density of striped catfish fingerlings in ponds was high and varied between to 476 000 to 503 000 fingerlings per ha per crop. The stocking densities depended on the size of seed stock. A high stocking density was considered as one of the key factors that contributed to the high productivity of striped catfish pond culture. However, the stocking density has gradually increased according to the developmental timeline. In the early days of pond culture, average stocking density was 205 000±100 000 fingerlings per ha (Nguyen *et al.,* 2004) but in recent years this has been increased to up to 480 000 fingerlings per ha (Phan *et al*., 2009). Despite the general increase in stocking densities, there have been no scientific studies to describe the effects of stocking densities on the productivity and growth of striped catfish under pond culture conditions. Although Phan *et al.* (2009) reported that there was no correlation between stocking densities and productivity, there is evidence to suggest that high stocking densities of small fingerlings results in low survival rates (P.N. Doan, Vinh Hoan Company, personal communication, 2009).

The average production cycle was between 8 to 9 months per crop. The production cycle of fish fed FMF and a combination of MPF and FMF was longer when compared to fish that were exclusively fed MPF (Table 2). The average productivity of striped catfish pond culture was 360 tonnes per ha per crop, which is high when compared with other culture species. According to Phan *et al.* (2009), the productivity of striped catfish varies from 70 to 850 tonnes per ha per crop (mean 406 tonnes per ha per crop), with 76 percent of the farms yielding 300 tonnes per ha per crop or more. Our survey showed that the productivity of fish fed FMF (398 tonnes per ha per crop) and a combined MPF and FMF (439 tonnes per ha per crop) was 22.4 and 25.9 percent higher respectively than the production from ponds fed MPF exclusively (325 tonnes per ha per crop).

Striped catfish nursery ponds averaged 0.44 ha (Table 3), which was similar in size to the grow-out ponds. However, the average water depth in the nursery ponds was 1.47 m which is lower than that recorded in the grow-out facilities. The nursery production cycle may be undertaken in either one or two stages. Seventy percent of nursery farms use a one-stage process, and the remaining 30 percent farms apply a two-stage process. The one-stage process takes an average of 2.7 months to complete (varying from 2.5 to 3 months) (Table 3), and the fish are nursed from larvae to a fingerling size of 1.5 to 1.7 cm (30–70 g). The two-stage nursery process takes approximately 3.5 months to complete (varying from 3 to 4 months), and the fish are nursed from larvae to fry in 1 to 1.5 months, and fry to fingerling in 2 to 2.5 months. The stocking densities and survival rates

for the first and second stage were 726±283 larvae per square meter and 33.3±7.4 percent; and 138±12.4 per square meter and 58.4±12.9 percent, respectively. Using the one-stage process, the average stocking density of larvae is relatively high (723±269 larvae per square meter); however, the average survival rate is correspondingly low (16.6 percent) (Table 3).

TABLE 3
General technical information of striped catfish farming in one stage nursery

Technical information	Values
Pond area (ha)	0.44±0.24
Pond depth (m)	2.15±0.62
Water depth (m)	1.47±0.39
Stocking density (fish/m^2)	723±269
Culture period (months)	2.70±0.36
Survival rate (%)	16.6±16.6

Notes: Numbers represent mean ± standard deviation; the stocking density, culture period and survival rate data of this table refer to one-stage nursery process.
Source: Field survey (2010).

3.3 Current feed use and feed management practices

There are two kinds of feed used in catfish farming in Viet Nam – manufactured pelleted feeds (MPF) and farm-made feeds (FMF). The MPF are produced as floating feeds with different sizes and formulations that are suited to the size of the fish. The FMF are sinking feeds that are prepared at the farm site using locally available ingredients. The feed usage in striped catfish production has changed overtime. In the early phase of sectoral development in the 1960s, the FMF was used for catfishes in cages, particularly for the Mekong catfish species (*Pangasius bocourti*) (Nguyen, 1998) but in recent years, MPF have replaced FMF.

3.3.1 Manufactured pelleted feeds

MPF were introduced to catfish cage culture systems in 1995–1996 by the Proconco Company. Initially, the feeds were poorly accepted by fish farmers as they were considered expensive and it was thought that their use would increase production costs. Moreover, catfish farmers have used farm-made feeds for several decades and traditionally were slow to change. In the late 1990s to early 2000s, many studies were conducted on the use of MPF for striped catfish, especially for pond culture. These studies investigated the potential to replace farm-made feeds, as farm-made feed use was becoming problematic in terms of ingredient availability. There was also a reduction in the availability of trash fish/low value fish. There were also needs to prevent the environmental pollution associated with their use, to improve the quality of the fish produced, and to ensure that a sustainable supply of feed was secured for the expansion of the sector. Since 2004, catfish farmers have gradually accepted the use of MPF; however, the level of acceptance depended on the location of the farms. For example, by 2004 in An Giang province, where striped catfish farming is most developed in the Mekong delta, 60 percent of catfish farm had shifted from FMF feed to a combined use of MPF and FMF (Tran, 2005); and by 2006, 50 percent of farms used MPF exclusively (Le and Pham, 2006).

The change from FMF to MPF has resulted in a significant increase in the number of aquafeed manufacturers in Viet Nam, and this has further exacerbated ingredient supply and cost issues for those farmers that still produce their own FMF, principally because the farmers could not buy ingredients at competitive prices. Tran (2005) reported that

there were 18 catfish feed manufacturers in operation in 2004 producing approximately 300 000 tonnes of MPF. However, by 2008 the number of registered catfish feed manufacturers had increased to 53 (various sizes). Currently, the total annual production capacity of these manufacturers is estimated to be 2 240 000 tonnes (Annex 1).

Depending on the manufacturer, MPF is produced in various size classes (Annex 2). There are 6 to 19 MPF size classes (Table 4). While some manufacturers are producing feed for both nursery and grow-out operations, many only produce grow-out feeds. The protein content of these feeds ranges between 18 percent and 40 percent, with small-sized (nursery) feeds containing a higher protein content (Table 5 and 6). The nutritional quality of the similar MPF size classes produced by different manufacturers is uniform (Table 5). The characteristics of a range of feeds from one randomly selected company are shown in Annex 3.

TABLE 4

Information of MPF from randomly selected feed companies

Feed company	Feed size (mm diameter)	Number of feed size classes offered	Crude protein content (%)*
UP	0.39–12.7	19	18–40
Cargill	1.8–10	11	22–28
Green Feed	2–12	18	20–28
Conco	powder–8	10	22–40
CP	2.5–12	8	20–30
Tongwei	powder–12	9	20–40
Ocialis	1.5–10	8	22–30
Dai Viet Hung	1–10	6	22–40

Note: *Data printed on feed bag and registered documents.

Source: Field survey (2010).

TABLE 5

The nutritional characteristics of MPF with similar feed size classes of four randomly selected companies (feeds for fish size of 100–400 g; as fed basis)

Composition	Tongwei Company	Proconco Company	CP Company	Viet Thang Company
Moisture (%)	10.4	11.3	8.6	9.84
Crude protein (%)	33.3	30.3	30.3	30.9
Crude lipid (%)	3.96	3.57	4.34	3.57
Ash (%)	10.1	9.99	14.1	10.8
Crude fibre (%)	7.65	4.19	9.03	5.74
Gross energy (kJ/g)	18	17.9	17.9	18
Pellet sizes				
- Length (mm)	3.54 ± 0.29	4.81 ± 0.27	4.56 ± 0.20	4.79 ± 0.35
- Diameter (mm)	3.21 ± 0.11	4.36 ± 0.18	4.44 ± 0.10	4.36 ± 0.23

Notes: Pellet sizes length and diameter are given in mean ± standard deviation; feed samples were analysed in the laboratory of College of Aquaculture and Fisheries, Can Tho University.
Source: Field survey (2010).

TABLE 6

The nutritional characteristics of MPF, feeding rate and feeding frequency of three randomly selected companies (feeds for nursery stage)

Items	Feed A	Feed B	Feed C
Crude protein (%)	≥40	≥40	≥42
Crude lipid (%)	≥5	≥6	≥5
Crude fibre (%)	≤3	≤6	≤6
Ash (%)	≤12	≤14	≤12
Moisture (%)	≤12	≤11	≤12
Phosphorus (%)	-	≥1	-
Feed type	powder/mash	particle	particle (<1 mm)
Fish size (g)	≤5	≤15	≤1
Recommended feeding frequency (% body biomass)	10–12	10–8	10
Recommended feeding rate (times per day)	6–8	5–6	5–15

Note: Data as specified on the feed bags.
Source: Field survey (2010).

The manufacturers use diversified ingredients to produce their feeds (Table 7), and these are dependent on seasonal supplies and prices. The most commonly used ingredients in MPF are fishmeal, soybean meal, rice bran, blood meal and meat and bone meal (MBM). The quantity of fishmeal used in MPF varies from 3 to 20 percent, depending on the feed sizes and protein level required. Fishmeal is expensive; therefore all manufacturers used other protein ingredients to partially replace fishmeal. These ingredients include soybean meal, blood meal and meat and bone meal. Studies have indicated that the protein digestibility of soybean meal, blood meal and meat and bone meal of striped catfish are 94.4 percent, 77.6 percent and 47.4 percent, respectively (Tran *et al.*, 2010). The energy supply for striped catfish feed is primarily derived from rice bran, and inclusion levels of this ingredient of up to 60 percent are used in the MPF formulations. While there are several kinds of rice bran available for striped catfish feeds, including dry full-fat rice bran, wet full-fat rice bran and de-fatted rice bran, the digestible levels of these ingredients are different. Moreover, inexpensive ingredients such as cassava and broken rice are also used in striped catfish diets as a source of carbohydrate. The dry matter digestibility of cassava and broken rice is 83.2 percent and 90.7 percent, respectively (Tran *et al.*, 2010).

TABLE 7

Nutritional values and digestibility of major feed ingredients used in the formulation of striped catfish MPF (percent dry matter)

Ingredient	Dry matter (%)	Crude protein (%)	Crude lipid (%)	Ash (%)	Nitrogen free extract (%)	Dry matter digestibility (%)	Protein digestibility (%)	Energy digestibility (%)
Fishmeal (65% protein)	91.9	65.3	6.19	19.1	-	87.7	96.1	93.9
Soybean meal	92.1	42.1	5.34	7.03	33.0	81.9	94.4	88
Blood meal	94.0	85	2	7	0	71.3	77.6	75.0
Meat and bone meal	-	50.0	16.1	23.0	8.59	74.1	74.4	70.9
Marine trash fish	24.4	17.8	1.42	4.00	1.14	89.1	94.5	96.4
Wet full-fat rice bran	88.0	11.8	13.6	5.90	54.7	81.5	67.6	84.2
Dry full-fat rice bran	90.7	12.8	18.9	9.07	43.9	62. 9	70.4	65.6
Defatted rice bran	90.4	14.9	1.72	9.49	5.82	56.7	66.4	54.5
Cassava	90.4	3.44	1.81	3.63	78.8	83.2	35.8	84.4
Broken rice	89.8	8.47	0.58	0.56	9.03	90.7	65.1	87.1

Sources: Compiled from Tran *et al.* (2010) and Nguyen and Tran (2008).

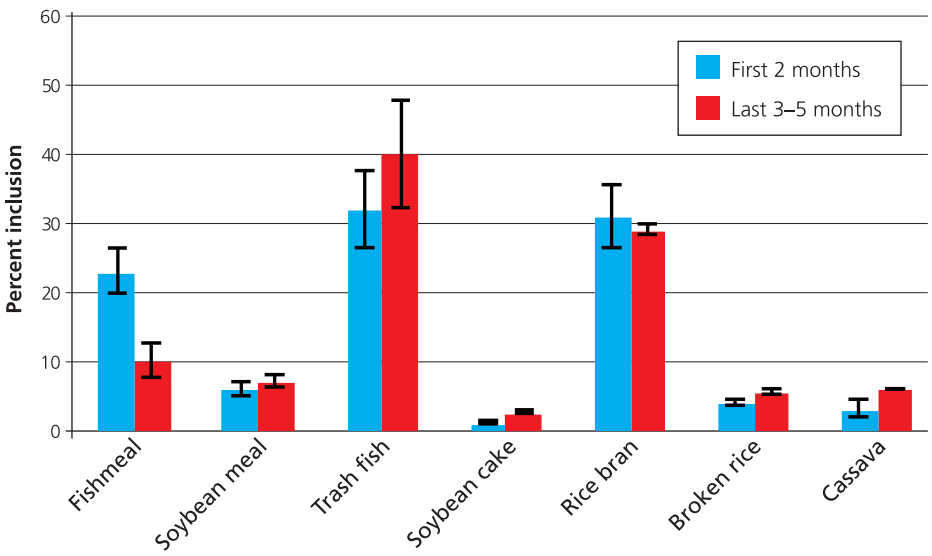
3.3.2 Farm-made feed

The FMF are formulated from inexpensive locally available feed ingredients including rice bran, broken rice, fresh trash fish and/or dried trash fish, soybean meal and fishmeal. The mixture of ingredients is cooked and extruded (Figure 5) to form a semi-moist pellet, which is fed directly to the fish within a day of manufacture. The quality of FMF is highly variable and is dependent on the quality of ingredients and the formulation of the diet. The crude protein level of the FMF during the first two months of the grow-out stage is usually higher than that which is used later in the grow-out cycle. Dietary crude protein levels vary from 19–25 percent, and are dependent on fish size. Nguyen (1998) found that the feed is normally formulated from 3 to 4 main ingredients such as trash fish, rice bran, broken rice and soybean meal. In recent years, the quality of FMF used for grow-out has improved significantly. This is a result of a diversification in feed ingredients, and formulations may now contain up to 6 or more primary ingredients (Figure 6). The FMF are either used for the full production cycle, or in combination with MPF. When used in combination, the MPF is used for the first two months of the production cycle or until the fish attain 100 g, and the last 1–2 months or until the fish reach approximately 800 g. The use of FMF throughout the production cycle is primarily limited to small scale farms.

FIGURE 5
Extrusion of farm-made feed (FMF) for grow-out striped catfish (*Pangasianodon hypophthalmus*)

COURTESY OF FAO/T.P. NGUYEN.

FIGURE 6
Formulations of farm-made feed for different grow-out stages of striped catfish



Source: Field survey (2010).

In addition, FMF are often used for broodstock as conditioning diets. In terms of broodstock feeds, 70 percent of the surveyed farms reported using FMF, and the remaining 30 percent used MPF. The feed formulations that are used for broodstock diets are relatively simple and are formulated from locally available ingredients (Table 8).

TABLE 8
Feed formulation for striped catfish broodstock

Ingredient	Dietary inclusion rate (%)
Dried trash fish	20.3±3.19
Fresh trash fish	40.8±5.98
Rice bran	30.2±4.11
Morning glory	10.8±5.34

Source: Field survey (2010).

3.3.3 The role of MPF and FMF in striped catfish farming

The use of MPF is very important for large and medium scale grow-out farms, where large amounts feed supplied on a regular basis are required. The use of MPF has been strongly recommended by government agencies due to their high quality and the associated levels of fish growth. Their use also results in a reduction in the potential for environmental pollution, improves the quality of the harvested product, and provides a mechanism for traceability. However, the disadvantage of using MPF is that they are expensive and the increased cost associated with their use can negatively affect the economics of the farming operation – particularly when the farm-gate price of the fish is low. The MPF industry is growing rapidly in Viet Nam, and in 2009, the total production capacity expanded to over 2 200 000 tonnes per annum. The MPF industry in Viet Nam is a highly competitive sector.

In contrast, government agencies have not recommended the use of FMF in striped catfish grow-out operations. Their use is discouraged due to concerns related to the formulations in use, potential nutritional imbalances, low water stability and concomitant concerns relating to the environmental impact of their use. However, the high price of MPF has forced a number of small-scale farmers to use FMF for at least some, or all of the grow-out cycle. Indeed – to reduce feed costs, some farmers that were previously using MPF reported that they reverted to using FMF when the farm-gate prices of fish were low. As a result of improved preparation techniques, the quality of FMF has been improved in terms of quality. The feed mixtures are cooked and extruded to form semi-moist pellets, which now have improved water stability (Figure 5).

3.3.4 Feed costs of striped catfish farming

The production costs during the grow-out stage are dependent on the type of feed that is used. The survey results confirm that feed costs, as a percentage of total production costs, are dependent on the type of feed used. MPF, FMF, or a combination of MPF and FMF accounts for 82.9 percent, 77.4 percent and 79.0 percent of total production costs, respectively (Table 9). However, calculated from this table, the average cost of feed was US$0.62 per kilogram of fish produced for the combined use of MPF and FMF; US$0.65 per kilogram for MPF, and US$0.68 per kilogram for FMF. Thus, the combined use of MPF and FMF increased the profits by US$0.03 per kilogram when compared to the use of MPF exclusively. This represents a significant cost saving, especially when the farm-gate price of the product is low. Generally, the price of MPF significantly affects both production costs and profits. Feed costs are high, and account for approximately 80 percent of total production costs (Nguyen and Dang, 2009). Nguyen *et al.* (2007) also stated that feed costs as a proportion of the total production costs were 92.4 percent when using MPF, 86.5 percent when a combination of MPF and FMF was

used, and 73.6 percent when FMF were used exclusively. Similarly, the survey found that feed cost accounts for 75.2 percent of the total nursery production costs (Table 10).

Improvement in feed utilization has been considered as the most effective way to reduce the production cost of striped catfish farming.

TABLE 9
Influence of different feed sources on production costs in striped catfish farming

Criteria	Overall (n=91)*	MPF (n=59)	FMF (n=15)	MPF+FMF (n=20)
Production cost (US$/kg fish)	0.800±0.125	0.789±0.149	0.877±0.247	0.790±0.231
Cost share (% total cost)				
Seed	5.4	4.5	7.5	7.1
Feed	81.3	82.9	77.4	79.0
Drugs and chemicals	4.0	3.8	4.6	4.2
Labour	2.3	2.3	2.1	2.4
Water pumping	1.4	0.9	2.1	2.0

*n= Number of respondents.
Source: Field survey (2010).

TABLE 10
Production costs of striped catfish farming in nursery phase

Criteria	Values (n=30)*
Production cost (US$/fingerling)	0.014±0.010
Selling prize (US$/fingerling)	0.022±0.009
Cost share (% total cost)	
Larvae (including transportation cost)	3.90±8.2
Feed	75.2±11.2
Drugs and chemicals	3.21±5.80
Labour	5.31±6.92
Gasoline and energy	2.56±2.94
Pond preparation	3.32±5.71
Other costs	4.71±6.72
Harvesting	2.24±3.21

*n= Number of respondents.
Source: Field survey (2010).

3.3.5 Feed prices and feed selection

Between 2008 and 2010 feed prices have reduced (Table 11). The price of MPF depends on the manufacturers, crude protein content, season and the prices of imported feed ingredients. The feed prices for FMF are difficult to estimate as they depend on the feed formulations and variations in ingredient prices (Table 12). However, the price of FMF feed is estimated at approximately US$0.237/kg to US$0.289/kg.

TABLE 11
The trend in feed prices according to crude protein level

Year	Crude protein (%) and feed costs (US$/kg)			
	30	26	20	18
2008	0.62±0.03	0.56±0.02	0.49±0	0.47±0.01
2009	-	0.50±0.04	0.48±0.01	0.41±0.03
Results of the survey (in 2010)	0.51±0.05	0.46±0.03	0.38±0.03	

Notes: Prices are given as mean ± standard deviation; the feed prices of 2008 and 2009 were recorded weekly from 4 selected companies.
Source: Field survey (2010).

TABLE 12
Feed ingredient prices

Feed ingredients	Price (VND/kg)	Price (US$/kg)
Fishmeal	16 875±3 216	0.888±0.169
Trash fish	3 670±1 244	0.189±0.065
Soybean meal	8 686±2 428	0.457±0.128
Soybean cake	1 300±1 240	0.068±0.065
Rice bran	3 607±821	0.161±0.043
Broken rice	4 453±1 355	0.234±0.071
Cassava meal	1 759±700	0.093±0.037

Note: Prices are given in mean ± standard deviation.
Source: Field survey (2010).

There are many criteria that farmers can use to select MPF. Of these, the reputation of the manufacturer and the feed price are the most important considerations. Other criteria such as payment schemes (credit schemes), feed conversion ratios and the availability of technical services from manufacturers are also taken into consideration. However, the large- and medium-scale farms usually select well-known brands. The MPF is distributed to the farm by various channels. These include direct distribution from the feed manufacturers, regional distributors, and retailers (Figure 7). Large-scale farms normally have contracts with feed manufacturers, and they benefit from lower prices when compared to those who buy the feed from distributors.

The cost of transportation of MPF or feed ingredients to the farm, either by the buyers or sellers, is dependent on the quantity or contract conditions. Feed sellers normally provide free transport of feed or feed ingredient to the farms. Vans and boats are main means of transport for feeds and ingredients (Figure 8). Feed storage is dependent on the facilities at individual farms. Large-scale farms have good storage facilities and can store large amounts of feed (Figure 9). However, small-scale farms normally have simple storage facilities that can only accommodate feeds that are bought on a weekly or bi-weekly basis. The feed ingredients that are used for FMF preparations such as rice bran, broken rice, soybean meal and cake and cassava meal are usually bought weekly or bi-weekly; trash fish are bought daily.

FIGURE 7
Distribution channels of manufactured pelleted feed (MPF)

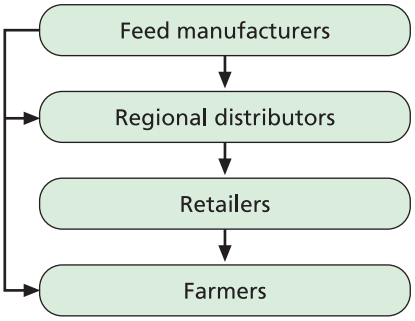


FIGURE 8
Feed transportation by boat

COURTESY OF FAO/T.P. NGUYEN.

FIGURE 9
Storage of manufactured pelleted feed (MPF) for grow-out striped catfish

COURTESY OF FAO/T.P. NGUYEN.

3.3.6 Feeding strategies

Feeding strategies depend on the types of feeds used and the size of the stock. The results of the survey revealed that the feeding rates using MPF vary from 2 to 5 percent body weight per day, and vary according to the size of the stock. The fish are fed at a rate of 5 percent when stock weighs less than 100 g, or the during the first two months of production; and at 2 percent when the stock weighs over 800 g or during the last 1.5 to 2 months of the culture cycle. The feeding rates between these sizes vary from 3 to 4 percent. At similar size classes, the feeding rates using FMF are approximately 1–2 percent higher than those rates that are used when feeding MPF (Table 13). Phan *et al.* (2009) reported that the average feeding rates of MPF for striped catfish were 5.6 percent, 3.2 percent and 2.0 percent body weight per day for months 1 and 2 of the production cycle, months 3 to 5, and months 6 and 7, respectively. Although the feeding rates are based on fish body mass, farmers usually feed to satiation.

The feeding frequencies that are used do not differ between the use of either MPF or FMF. Multiple-feeding frequencies are used when feeding small-sized fish. Fish are usually fed 3 times a day when small (<100 g), and 1–2 times for larger-sized fish (>100 g to harvest size) (Table 13). In addition to feed quality, feeding frequency is important in terms of improving feed conversion ratios. The feeding method differs according to feed type, i.e. either MPF or FMF. MPF are usually broadcast over the pond surface from boats, while FMF are fed at a specified feeding places or stations (Figure 10).

FIGURE 10
Feeding grow-out striped catfish with farm-made feed from a feeding station (top left), feeding with manufactured pelleted feed from a floating raft (top right) and fish coming in the surface during feeding (bottom centre)

COURTESY OF FAO/T.P. NGUYEN.

TABLE 13
Feeding rates and frequencies used in striped catfish in grow-out phase

Culture months and fish sizes	Feeding rate (% BW)	Feeding frequency (time/day)
Month 1st and 2nd (<100 g)		
Manufactured pelleted feed (MPF)	5–6	3 (08.00 hours, 10.00 hours and 17.00 hours)
Farm-made feed (FMF)	6–7	
Month 3rd to 5th (>100 to 800 g)		
Manufactured pelleted feed (MPF)	2–3	2 (09.00 hours and 15.00 hours)
Farm-made feed (FMF)	4–5	
Month 6th and 7th (800 g to harvest)		1 (14.00 hours)
Manufactured pelleted feed (MPF)	1.5–2	
Farm-made feed (FMF)	3.5–4	

Source: Field survey (2010).

The survey showed that all catfish nursery farmers used MPF. For the past 3–4 years, MPF for larval, fry and fingerling diets have been commercially available. The feeding rates and frequencies applied to nursery production are provided in Table 14. Fish are fed an average of 10.7 percent of body weight per day for the first 25 days and the rate is eventually reduced to an average of 6.05 percent of body weight per day in the final 45-day phase before harvesting (Figure 11). These feeding rates are much higher than those used in grow-out production. The feeding frequency is also dependent on the production cycle, and fish are fed 3 times per day for the first 25 days of the production cycle and twice per day thereafter.

FIGURE 11
Harvest of striped catfish (*Pangasianodon hypophthalmus*), Mekong Delta, Viet Nam

COURTESY OF FAO/T.P. NGUYEN.

The feeding rate for broodstock varies according to the culture period. Fish are fed 4 to 5 percent of body weight per day during the preparatory conditioning period, and 1.5 to 2 percent for the maturation and spawning periods.

TABLE 14
Feeding rates and frequencies used in striped catfish in nursery phase

	Feeding rates (% BW)	Feeding frequencies (time/day)
Day 1st to 25th	10.7±3.19	3 (73.9% surveyed farms applied)
Day 26th to 45th (~0.5 g/fish)	8.14±5.98	2 (78.5% surveyed farms applied)
Day 46th to 90th (30 g/fish)	6.05±4.11	2 (96.3% surveyed farms applied)

Source: Field survey (2010).

The feed conversion ratios (FCR) recorded during the grow-out cycle differed according to the feed types that were used. The FCR derived from the MPF and FMF averaged 1.6:1 and 2.9:1 respectively (Table 15). There have been a number of reports relating to the FCR derived from MPF and FMF in striped catfish farming. In 2009, 27 grow-out farms using MPF reported an average FCR of 1.63, and maximum and minimum FCR at 1.71 and 1.52, respectively (P.N. Doan, Vinh Hoan Company, personal communication, 2009). Phan *et al.* (2009) reported that the FCR of MPF varied from 1.0:1 and 3.0:1 (average of 1.69:1), while for FMF, FCR ranged between 1.3:1 and 3.0:1 (average 2.25:1). The variation in the FCR is mainly a result of the survival rates of the fish attained; and of the quality of feeds and the feeding strategies that are applied. These reported data indicate that the FCR of MPF in striped catfish farming have not changed significantly over the past few years.

TABLE 15
Feed conversion ratios of striped catfish fed different feed types

Feeding categories	Number of respondents	FCR
Manufactured pelleted feed (MPF)	69	1.6±0.16
Farm-made feed (FMF)	19	2.9±0.62
A combination of manufactured pelleted feed and farm-made feed (FMF)	21	2.9±0.65

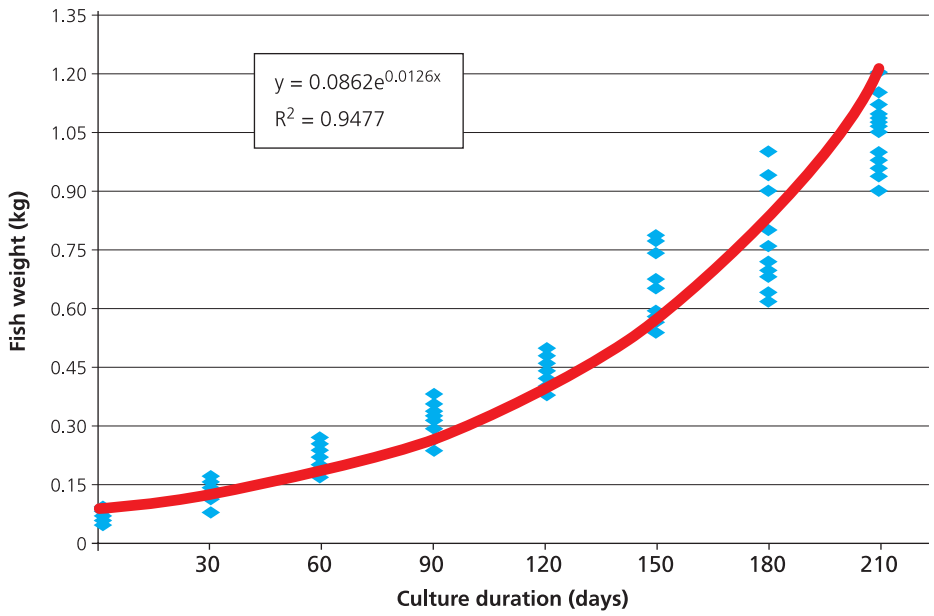
Note: FCR are given in mean ± standard deviation.

Source: Field survey (2010).

3.4 Growth performance of striped catfish

The growth performance of striped catfish varies according to the feeding practices employed. The production cycle of the fish fed MPF is about one month shorter than those fed other feeds or feed combinations (Table 2). Figure 12 illustrates a growth curve of striped catfish fed MPF that was collected from fourteen ponds (monthly sampling). Using these diets, and at an initial stocking size of around 50 g, the fish reach a marketable size after six to seven months.

FIGURE 12
Growth of striped catfish fed manufactured pelleted feed



Source: Computed from data collected during field survey (2010).

3.5 Cost benefit analysis

Catfish production requires a high level of investment. A cost/benefit analysis of striped catfish farming is presented in Table 16. The total production cost per ha depends on the stocking density. Currently, average net income is negative for farmers that use FMF or a combination of MPF and FMF, and is very low for the farms that use MPF exclusively. The average production cost per kg fish for all types of feeding categories was just over US$0.8/kg. Average production costs were lowest for those systems that used MPF exclusively (US$0.789/kg), and highest for those systems that used FMF exclusively (US$0.877/kg).

Between 49.2 to 73.3 percent of farms that were surveyed were losing money, especially those that exclusively used FMF (73.3 percent). The low profitability was attributed to a significant drop in the farm-gate price for the fish in 2009. The farm-gate price of marketable sized fish fell from around US$0.053 to 0.063 per kilogram of fish at the time of survey. Le (2008) reported that only 11.6 percent of farms encountered financial losses in 2008.

TABLE 16
Cost benefit analysis of striped catfish farming

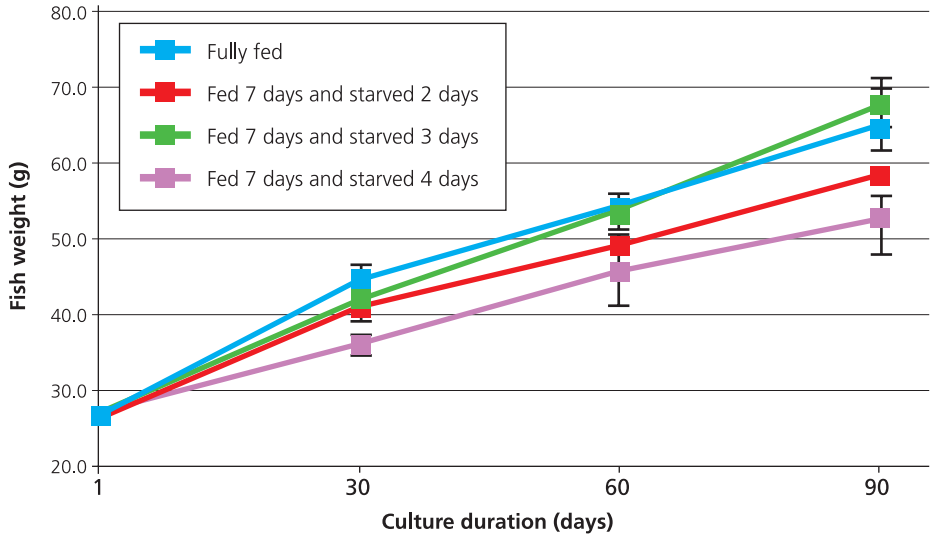
Criteria	Overall (n=91)*	MPF (n=59)	FMF (n=15)	MPF+FMF (n=20)
Productivity (tonnes/ha/crop)	360±162	325±153	398±137	439±188
Gross income (US$/ha)	281263±128 789	255 947±129 053	312 368±103 632	327 684±133 211
Total cost (US$/ha)	288 368±140579	253 789±124 842	351 632±124 158	335 842±169 158
Net income (US$/ha)	-7.05±51.2	2.11±37.16	-39.2±60 789	-8.10±69 789
Selling price (US$/kg)	0.789±0.05	0.791±0.052	0.786±0.055	0.777±0.043
Production cost (US$/kg)	0.804±0.125	0.789±0.149	0.877±0.247	0.795±0.231
Farms experiencing losses (%)	55	49.2	73.3	55
Farms in profit (%)	45	50.8	26.7	45

Notes: Values are given in mean ± standard deviation; *n: number of respondents.
Source: Field survey (2010).

3.6 New innovations in feeding strategies

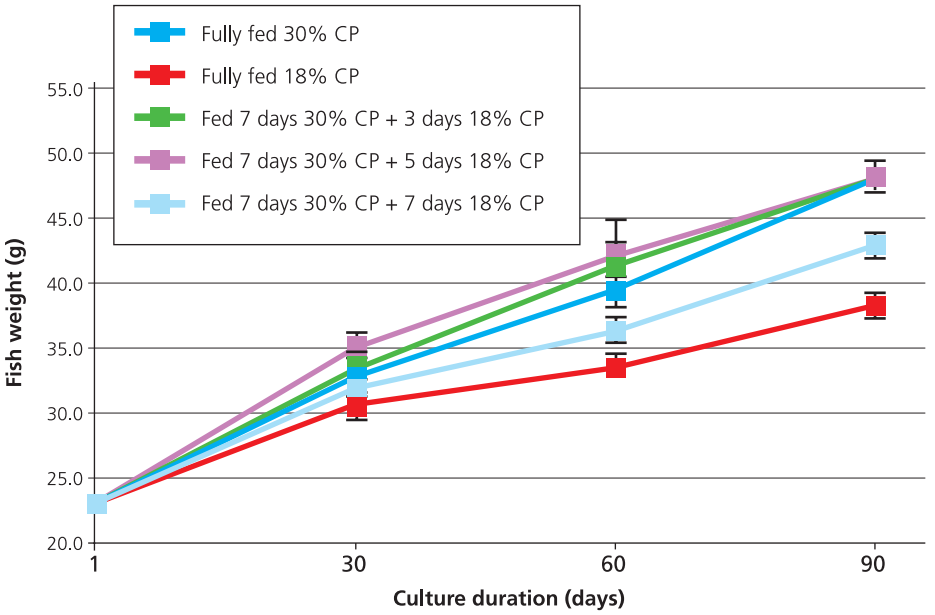
Over time, feeding strategies that are used in striped catfish production have changed as a result of the experience of farmers and of research. The FCR of striped catfish fed MPF improves when the feeding frequency is reduced from twice to once per day (H.D. Nguyen, Vemedim Company, personal communication, 2009). Similar findings have established that the feed cost per unit of fish production can be reduced by 3.33 percent if one feeding of MPF is applied throughout the production cycle.

FIGURE 13
Growth of striped catfish fed different restricted feeding regimes



Note: Error bars represent standard error of the means
Source: Duong, Ly and Nguyen (2011).

FIGURE 14
Growth of striped catfish fed different alternate feeding regimes of high and low protein manufactured pelleted feeds



Note: Error bars represent standard error of the means; CP = crude protein
Source: Duong, Ly and Nguyen (2011).

In such cases, the production cycle is prolonged by approximately four weeks (H.N. Nguyen, Thoi An catfish culture cooperative, personal communication, 2010). Duong, Ly and Nguyen (2011) reported that fish growth and feed conversion ratios can also be improved by applying novel feeding strategies such as restricting feeding regimes and using alternate regimes. The growth of fish fed a restricted feeding regime in which the fish were fed for 7 days and subsequently starved for 3 days was not significantly different to the growth rates derived from fish that has been fed on a continuous basis ($p>0.05$) (Figure 13). Furthermore, the FCR of the fish that had been placed under a restricted feeding regime was reduced by 18 percent. In addition, the growth rate of striped catfish fed alternate feeding regimes of 30 percent protein MPF for 7 days and 18 percent protein MPF for 3 or 5 days were not significantly different to fish that were fed 30 percent protein MPF all of the time ($p>0.05$) (Figure 14).

4. RESEARCH NEEDS

Currently, MPF are the majority type of feeds that are used for striped catfish production, with FMF still being used by small-scale farmers. Feed cost is a key factor affecting the profitability of striped catfish farming, and there are still a number of issues related to feeds that warrant attention in terms of improving feed utilization, and reducing pollution and nutrient loads into the environment.

The rapid growth of the feed industry during the past few years has seen the availability of different feeds on the market increase. The feed quality information that manufacturers are required to publicize includes basic proximate composition but other important factors, such as the digestibility of dry matter, crude protein and energy, are not reported. In this regard, research to determine the digestibility of feed ingredients used in feed formulations in MPF and FMF needs to be prioritized. Moreover, the development of proper methodologies to assess the digestibility of MPF and FMF under production conditions would be useful and highly valuable.

The FCR derived from the diets used in striped catfish culture in the surveyed farms varied from 1.6:1 for MPF to 2.9:1 for FMF. The protein content of feeds fed to larger sized fish is lower than the nutritional requirements of small striped catfish; fish that are <10 g have a protein requirement that is between 29.5 and 38 percent (Hung *et al.*, 2002; Tran *et al.*, 2004). A current study at Can Tho University, Viet Nam indicates that the protein requirement for striped catfish is reduced from 39 percent to 24 percent for stock sizes from 10 g to 1 000 g (unpublished data). Additional research on the nutritional requirements of the larger sizes of striped catfish is required to optimize formulations.

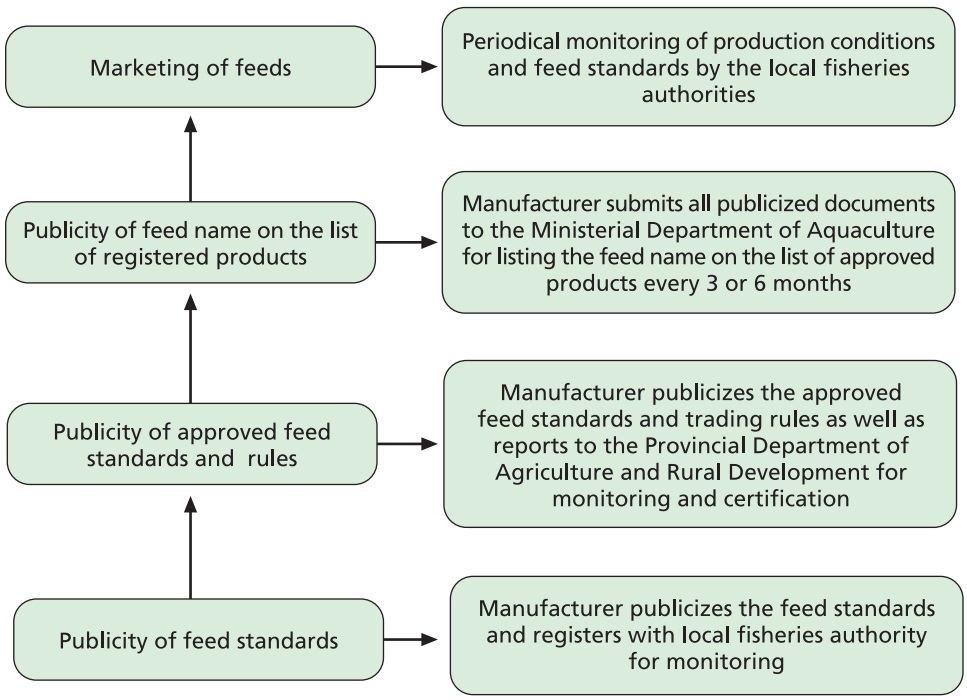
Feeding frequency is also an important factor contributing to the improvement of feed utilization and FCR reduction. In this regard, the feeding frequencies that are currently employed are not supported by scientific research. Research into feed use including feeding frequencies and the quality of FMF is required. In addition, the complete or partial use of FMF could prove to be an effective way to reduce feed costs. This is particularly important to small-scale farmers who have limited access to capital.

5. REGULATORY FRAMEWORK

The recent decree of the central government of Viet Nam (Decree No. 08/2010/NĐ-CP) provides a new detailed regulatory framework for manufacturing and trading in aquafeeds. Principally, the manufacturers are required to publicize the quality of feeds before the feeds are produced and commercialized. There are several steps that are required before the feeds can be traded (Figure 15). The local fisheries authorities are responsible for the approval and monitoring of feed quality and the production conditions of each manufacturer. This new regulatory

framework offers the manufacturers many advantages in that it simplifies the feed registration process and enables them to develop and improve their aquafeeds. The previous regulatory framework was complicated and included laboratory and pilot-scale tests of the feed quality before the feeds could be registered. At present, there is no regulatory framework to control feed prices. The manufacturers are only required to publicize the prices of their commercialized feeds. In practice, feed price is regulated by competition between the manufacturers/companies. There could be a need to regulate aquafeed prices in the future in order to support the sustainable development of the striped catfish industry.

FIGURE 15
Regulatory framework of feed manufacturing and quality control



Source: Adapted from Government of Viet Nam (Decree No. 08/2010/NĐ-CP).

6. CONCLUSIONS

Feed management of striped catfish farming in Viet Nam has changed markedly over the past ten years. The greatest change has been the shift from farm-made feeds to manufactured pelleted feeds. In recent years, the manufactured pelleted feed industry has expanded rapidly, and the production capacity of the existing manufacturers currently meets the demand of the striped catfish farming sector. However, feed costs represent the highest proportion of the total production costs, and they therefore constitute a major factor affecting the profitability of farming operations. Research to improve feed management for striped catfish is urgently required to improve the profitability and sustainability of the striped catfish farming sector in Viet Nam.

ACKNOWLEDGEMENTS

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ANNEX 1
List of manufacturers in Viet Nam

No.	Company	Estimated production in 2009 (tonnes)
1	CP	120 000
2	Viet Thang	100 000
3	Cargill	80 000
4	Novafeed	50 000
5	Tay Nam	150 000
6	Proconco	120 000
7	Greenfeed	60 000
8	Viet Long	30 000
9	Kien Thanh	30 000
10	Master	40 000
11	Co May	40 000
12	ViNa	50 000
13	UP	70 000
14	Ando Group	40 000
15	Tomboy	30 000
16	Vinh Hoan	75 000
17	Bluestar (ABS)	50 000
18	Cataco	50 000
19	Hiep Thanh	50 000
20	TongWei	50 000
21	Minh Quan	30 000
22	Dai Hung	35 000
23	Ocialis	30 000
24	Nutrifarm	30 000
25	Anco	30 000
26	CCP	30 000
27	Song Tien	50 000
28	Kim Anh	50 000
29	Cuu Long	50 000
30	Woosung	40 000
31	Forca – Biofeed	30 000
32	Growbest	40 000
33	Thanh Loi	30 000
34	Truong Son	30 000
35	Viet Anh	30 000
36	Nam Tien	30 000
37	A Chau	30 000
38	AFIEX	30 000
39	Bình An	30 000
40	Kim Xuan	30 000
41	Viet Bi	30 000
42	Viet Thai	30 000
43	Ha Lan	30 000
44	Con Heo Vang	30 000
45	Harvest	30 000
46	Nafatsco	30 000
47	Hanco	25 000
48	Viet Duc	25 000
49	Do Loc	20 000
50	My Tuong	20 000
51	Viet Dan	60 000
52	Domyfeed	30 000
53	FBT	30 000
54	Hoàng Long	30 000
	Total	**2 240 000**

ANNEX 2
Details of MPF of four selected large-scale manufacturers (in 2009)

Viet Thang Company

No.	Fish sizes (g/fish)	Feed size classes	Protein (%)	Feed sizes (mm)	Price (US$/kg)
1	<10	VT1	40	1	0.614
2	<14	VT1	40	1.5	0.593
3	<10	VT2	35	1	0.536
4	<14	VT2	35	1.5	0.508
5	<10	VT3	32	1	0.505
6	<14	VT3	32	1.5	0.475
7	<10	VT4	30	1	0.475
8	<14	VT4	30	1.5	0.454
9	<14	VT5	28	1.5	0.428
10	14–300	VT5	28	2.2–4	0.405
11	80–300	VT6	26	3–4	0.382
12	300–600	VT6	26	5–8	0.377
13	300–600	VT7	24	5	0.366
14	150–300	VT8	22	4	0.356
15	300–1 000	VT8	22	5–8	0.351
16	>1 000	VT9	18	8	0.334

Notes: Prices are at the manufacturing gate; data are specified on the bags and registered documents.

Concon company

No.	Fish sizes (g/fish)	Feed size classes	Protein (%)	Feed sizes (mm)	Price (US$/kg)
1	3–15 day-old	5001	40	Powder	0.701
2	16–30 day-old	5002	35	Powder	0.694
3	16–30 day-old	5002	35	Granules	0.580
4	16–30 day-old	5002	35	1–1.5	0.711
5	4–14 g	5004	32	1.5	0.554
6	14–150 g	5005	28	1.5	0.495
7	14–150 g	5005	28	2.2	0.449
8	14–150 g	5005	28	3–4	0.447
9	150–300 g	5006	26	5–8	0.391
10	300–600 g	5007	22	5–8	0.365

Notes: Prices are at the manufacturing gate; data are specified on the bags and registered documents.

Uni-President – UP company

No.	Feed size classes	Feed sizes (mm)	Protein (%)	Price (US$/kg)
1	T501S	<40 mesh	40	0.662
2	T501	18–40 mesh	40	0.662
3	T502S	14–18 mesh	40	0.662
4	T502	1.5–1.7	40	0.662
5	T503	2–2.2	40	0.609
6	T503SL	2–2.2	30	0.501
7	T503S	3–3.2	30	0.496
8	T504	4.3–4.7	30	0.488
9	T50426-3	3–3.2	26	0.416
10	T50426-4	4.3–4.7	26	0.405
11	T504S	5.3–5.7	26	0.405
12	T50426-6D	6.3–6.7	26	0.403
13	T50426-9D	9.3–9.7	26	0.403
14	T50426-12D	12.3–12.7	26	0.403
15	T505SL	3–3.2	22	0.395
16	T505S	4.3–4.7	22	0.389
17	T505	6.3–6.7	22	0.384
18	T50522-9D	9.3–9.7	22	0.382
19	T50522-12D	12.3–12.7	22	0.382

Notes: Prices are at the manufacturing gate; data are specified on the bags and registered documents.

Cargill Company

No.	Fish sizes (individual weights)	Feed size classes	Protein (%)	Price (US$/kg)
1	20–200 g	3	26	0.512
2	200–500	4.3	26	0.506
3	500 g – harvest	10	20	0.441
4	500 g – harvest	6–10	22	0.483
5	500 g – harvest	6–10	22	0.475
6	500 g – harvest	6–10	24	0.488
7	500 g – harvest	6–10	20	0.462
8	20–200 g	1.8	28	0.596
9	20–200 g	3	26	0.531
10	200–500 g	4.5	25	0.530
11	500g – harvest	6	22	0.504

Notes: Prices are at the manufacturing gate; data are specified on the bags and registered documents.

ANNEX 3
Details of quality of MPF from a randomly selected company

Feed size classes	Moisture (%)	Crude protein (%)	Crude lipid (%)	Ash (%)	Fibre (%)	Feed sizes (mm diameter)
T501	10	40	4	12	5	<0.39
T501S	10	40	4	12	5	0.39–1.06
T502	10	40	4	12	5	1.06–1.41
T502S	10	40	4	12	5	1.5–1.7
T503	10	40	4	12	6	2.0–2.2
T503S	10	40	5	12	6	3.0–3.2
T504	10	30	5	12	6	4.3–4.7
T504S	10	26	5	12	6	5.3–5.7
T505	10	22	5	12	6	6.3–6.7
T506(S)	10	20 (18)	5	12	6	9.3–9.7
T507(S)	10	20 (18)	5	12	6	12.3–12.7

Notes: Data are as specified on the bags.

On-farm feed management practices for giant river prawn (*Macrobrachium rosenbergii*) farming in southwest Bangladesh

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ABSTRACT

This paper examines feed management practices for giant river prawn (*Macrobrachium rosenbergii*) farming in three production systems in southwest Bangladesh. Based on the production technology, prawn farming is classified either as extensive, improved-extensive or semi-intensive. Most farmers farm prawns in rice fields, and are primarily dependent on prawn, fish, rice and dike crops. Prawn farmers using extensive feeding practices depend solely on snail meat. The improved-extensive farming systems use farm-made aquafeeds comprising mixtures of locally available feed ingredients (e.g. rice bran, mustard oil cake, fishmeal, oyster shell, salt and vitamins). Prawn farms based on semi-intensive feeding practices use industrially manufactured pelleted feeds. The average annual prawn production using semi-intensive farming systems was 718 kg/ha, representing higher yields than the improved-extensive (489 kg/ha) and extensive (351 kg/ha) farming systems. The improved yields were mainly attributed to higher levels of inputs, including seed, feed, fertilizer and labour. On semi-intensive farms, the average annual production cost was estimated at US$2 875/ha. In improved-extensive systems, production costs were US$2 088/ha, and in extensive systems they were US$1 457/ha. Feeds constitute the second highest operational cost in extensive (15 percent) and improved-extensive (25 percent) farming, and the highest operational cost in semi-intensive farming (33 percent). Despite the higher production costs per hectare, the average annual net return was higher in semi-intensive farming (US$2 162), compared with improved-extensive (US$1 445) and extensive (US$1 092) farming.

The low production costs associated with the use of snail meat in extensive farming makes it a suitable feed source for resource-poor farmers. However, relatively low levels of production and net returns are attained. Moreover, in the long term, supply issues and the environmental costs associated with snail harvesting may make the practice unsustainable. Higher net returns per hectare were obtained using semi-intensive farming systems. In these systems, producers appear to be able to afford more inputs, including industrially manufactured pelleted feeds. The high level of investment required to develop

semi-intensive farming systems suggests that this type of farming would not be possible for resource-poor, small-scale farmers. The quality of industrially manufactured pelleted feeds that are available is of concern, and in particular, the presence of banned antibiotics. It is therefore recommended that farm-made aquafeeds provide the best feed choice for resource-poor farmers in terms of availability, quality and price. This article concludes that farm productivity as well as profitability can be increased through increasing the feeding rates of farm-made aquafeeds and improving feed management practices.

1. INTRODUCTION

The giant river prawn (*Macrobrachium rosenbergii* De Man 1879)[1] is the most widely cultured and distributed freshwater prawn. It is widely distributed throughout the tropics, the sub-tropics and temperate zones. It is indigenous to South and Southeast Asia, as well as in northern Oceania and the western Pacific Islands. *M. rosenbergii* is the species most commonly used for commercial prawn production[2], and it is now farmed in many countries, including Australia, Bangladesh, Brazil, China, Ecuador, Honduras, India, Indonesia, Israel, Malaysia, Mauritius, Mexico, the Philippines, Thailand, Viet Nam and the United States of America (New, 2002). In spite of its widespread distribution, freshwater prawn culture has been less important in terms of volume and value than marine shrimp[3] culture. In 2010, global farmed production of all species of river prawns (*Macrobrachium* spp.) was 450 158 tonnes, of which giant river prawn production was 215 029 tonnes (FAO, 2012) In Asia, farmed giant river prawns are primarily cultured in Taiwan Province of China, Thailand and Viet Nam (New, 2005). In 2010, China was the largest producer of *M. rosenbergii*, producing 125 203 tonnes equating to 58 percent of global production. Bangladesh was the third largest global producer, producing 30 636 tonnes equating to 14 percent of global production (FAO, 2012).

Due to its favourable climate and water resources, Bangladesh is considered one of the most suitable countries in the world for giant river prawn (*Macrobrachium rosenbergii*) farming. The sub-tropical climate and vast areas of shallow water provide a unique opportunity for the growth of many species of freshwater prawns. Twenty four species of freshwater prawn including 10 species of *Macrobrachium* are found in Bangladesh. However, only *M. rosenbergii* has significant aquaculture potential and is commercially cultured (Ahmed, Demaine and Muir, 2008). Within the overall agro-economy in Bangladesh, *M. rosenbergii* farming is currently one of the most important sectors and, during the last three decades, its development has attracted considerable attention in terms of its export potential. The freshwater prawn is a highly valued product in international markets, and almost all cultured prawns reared in Bangladesh are exported. Major export markets include the United States of America, Europe and Japan. In 2010/11[4], Bangladesh exported 54 891 tonnes of prawn and shrimp valued at US$446 million, of which 30 percent was attributed to prawns (DoF, 2012). The sector represents the largest agro-export sector, and after the garments sector, the second largest export earner. Approximately 1.2 million people are directly involved in prawn and shrimp production, processing and marketing, and a further 4.8 million household members are associated with the sector. In addition, the livelihoods of around 400 000 people, many of them women and children, are associated with prawn and shrimp

[1] The term 'freshwater prawn' generally refers to the genus *Macrobrachium*, a large genus of crustaceans comprising over 200 species. *M. rosenbergii* is the largest *Macrobrachium species*, and is officially known as the giant river prawn. The maximum recorded size for males and females of this species is 33 cm and 29 cm, respectively (New, 2002).

[2] The oriental river prawn (*Macrobrachium nipponense*) had a production level greater than the production of giant river prawns in 2010 (FAO, 2012) but is only reared in China.

[3] The term 'prawn' is used for freshwater species and 'shrimp' for marine and brackishwater organisms.

[4] Bangladesh fiscal year: 1 July – 30 June.

fry fishing in coastal Bangladesh (USAID, 2006). Unfortunately the number of people involved in prawn farming is not precisely known as the national statistics have not, until very recently (M. New, personal communication, 2012), distinguished between the prawn and shrimp sub-sectors. From a variety of published sources and personal communications with relevant government departments, it is estimated that around 600 000 people are directly involved in prawn farming, marketing and associated activities; this includes 120 000 farmers and 200 000 on-farm labourers (Ahmed, 2009). Prawn processing and marketing also provides economic returns, social benefits and livelihood opportunities to thousands of the rural poor (Islam, 2008; Ahmed *et al.,* 2009).

The total area under prawn cultivation in Bangladesh is estimated to be around 62 875 ha – about a fourth of the 276 492 ha that are available for shrimp farming (DoF, 2012). The majority of prawn farms (>75 percent) are located in southwest Bangladesh, mainly in Bagerhat, Khulna and Satkhira districts, with the remainder in the southeast region. Small-scale prawn farming in rice fields is widespread in southwest Bangladesh, where wild postlarvae (PL)[5] are available, and there are favourable resources, including low-lying rice fields and a warm climate (Ahmed, Demaine and Muir, 2008). In Bangladesh, freshwater prawn farming first started in the southwest region in the early 1970s (Mazid, 1994). The most significant developments have taken place in Bagerhat district, where thousands of farmers have converted their rice fields to prawn farms, locally known as '*gher*' (Kendrick, 1994; Rutherford, 1994). In Bengali, the term '*gher*' means an enclosure that is designed for prawn cultivation. This is achieved by modifying existing rice fields, building higher dikes, and excavating a canal several feet deep inside the periphery to retain water during the dry season. *Gher* farming is a 'quiet, indigenous technological revolution' suitable for the cultivation of prawns, fish and rice.

Innovative prawn farming in rice fields, combined with high prawn prices in the international markets, and rice and fish for household consumption, has led to increasing numbers of farmers converting their rice fields to prawn farms. The early innovators tended to be large and medium size farmers, but increasingly small and marginal farmers have also started farming prawns with fish in their rice fields (Rutherford, 1994). Since 1990, the prawn sector has grown rapidly and has spread to other southwest districts, such as Khulna and Satkhira, where prawn farming has now become one of the most attractive investment opportunities (Ahmed, Demaine and Muir, 2008). As a result of social, economic and technological constraints, including an inadequate supply of prawn fry, high seed and feed costs, prawn farming is marginal in the rest of the country. Feed management is also of grave concern for the expansion of the sector.

This paper examines various feeding practices used in prawn farming in Bangladesh. Prawn production comprises different feeding systems which are dependent upon the level of farming technology. The use of industrially manufactured aquafeeds in prawn culture elicits higher production levels, increases production costs, and improves financial returns (Ahmed, Demaine and Muir, 2008). Typically, resource-poor farmers are constrained by a lack of capital or inadequate technical knowledge, and thus they adopt lower cost input systems that are based on farm-made aquafeeds (mixtures of rice bran, oil cake and fishmeal) and snail meat. The present case study provides a comparative analysis of using three different feed types, namely: (1) snail meat, (2) farm-made aquafeeds[6] and (3) industrially manufactured pelleted feeds.

[5] The term 'postlarvae' usually applies to animals from the time of metamorphosis up to about 60 days later. The terms postlarvae and fry are used interchangeably in this paper.

[6] The local abundance of certain raw materials is naturally reflected in their use for aquafeed production.

2. METHODOLOGY

2.1 Study area

The study was conducted in the Bagerhat district, a coastal area of the Bay of Bengal, situated in the southwest part of Bangladesh (Figure 1). Geographically, Bagerhat has been identified as the most important and promising area for prawn culture. This is due to the availability of wild PL, the climatic conditions and favourable resources, including low-lying rice fields, fertile soils, and cheap and abundant labour (Ahmed, Demaine and Muir, 2008). The district is divided into nine sub-districts[7]; among them Bagerhat Sadar, Fakirhat, Mollahat and Chitalmari primarily culture *M. rosenbergii*. As a result of salt-water intrusion, the remaining sub-districts primarily culture tiger shrimp (*Penaeus monodon*). Among the four prawn farming sub-districts, Fakirhat is the most important – prawn farming was first started in this area in the early 1970s (Mazid, 1994). Though the sector has developed well in other areas, the number of prawn farms and farmers is still the highest in the Fakirhat area. For the people of Fakirhat, prawn production in rice fields was reported to have increased the incomes of subsistence farmers considerably (Ahmed, Allison and Muir, 2010). Fakirhat was therefore selected as the focus area for the study.

FIGURE 1
Map of Bangladesh showing the study area

Source: Banglapedia [http://banglapedia.com/].

2.2 Data collection

The field research was conducted between December 2009 and March 2010. Combinations of participatory, qualitative and quantitative methods were used to collect the primary data.

2.2.1 Questionnaire interviews

Questionnaire interviews with the prawn farmers were preceded by the preparation and testing of the questionnaire, and enumerator training. Pilot testing of the questionnaire was carried out with ten prawn farmers. The aim of the pilot survey was to ensure that the questions were clear of ambiguities, and that the respondents could answer the questions easily. Based on the results of the pilot survey, the questionnaire was modified and improved.

Farmers were selected through a stratified random sampling process that was based on the feeding strategies that they used. The farmers were classified into three groups according to the type of feed they used, *viz.* (1) snail meat, (2) farm-made aquafeeds and (3) industrially manufactured pelleted feeds

[7] Bagerhat district is divided into nine sub-districts, namely: (1) Bagerhat Sadar, (2) Fakirhat, (3) Mollahat, (4) Chitalmari, (5) Kachua, (6) Rampal, (7) Morelganj, (8) Mongla and (9) Sarankhola.

(Table 1). A simple random sampling technique was used to identify the famers that were included in the survey. A total of 90 prawn farmers, 30 in each stratum, were interviewed at their houses and/or farm sites. A more focused comparative examination of the three different feeding strategies was performed. Several visits were made to selected farmers to observe feeding practices. These visits were also useful for building up a rapport with the farmers; this assisted with the questionnaire interviews. The interviews focused on prawn farming systems, feeding strategies, feed management, feed marketing, feeding constraints, productivity, production costs and returns, and the socio-economic status of the farmers.

TABLE 1
Stratification of prawn farmers based on feeding systems

Feeding category	Sample size	Farming system	Characteristics
Snail meat	30	Extensive	Small farms (less than 50 decimals or 0.20 ha), resource-poor, using lower inputs (seed, feed, fertilizer and labour), typically subjected to financial constraints
Farm-made aquafeed	30	Improved-extensive	Medium farms (51–100 decimals or 0.21–0.40ha), intermediate inputs, typically requiring production loans
Industrially manufactured pelleted feed	30	Semi-intensive	Large farms (above 100 decimals or 0.41 ha), using higher inputs, typically using their own financial capital

Source: Field survey (2010).
Note: Land area in Bangladesh is commonly expressed as decimals; 1 ha of land = 247 decimals.

2.2.2 Participatory rural appraisal

In the current study, the PRA (Participatory Rural Appraisal) tool Focus Group Discussion (FGD) was conducted with prawn farmers and associated groups, including women, children and day labourers. FGD is a group meeting where people from the target communities discuss selected topics (Conroy, 2002). A total of 15 FGD sessions were conducted for this study with each group comprising between 6 and 12 persons (total: 131 people). FGD was used to provide an overview of prawn farming practices, on-farm feed management, feeding systems, feed procurement, feed quality and feeding issues. The method was also used to verify the information provided from the questionnaire interviews.

2.2.3 Rapid market appraisal

Rapid Market Appraisal (RMA) is an efficient way to obtain policy-relevant and intervention-focused information about commodity sub-sectors (Holtzman, 2003). RMA techniques primarily rely on interviews with knowledgeable sub-sector observers/actors. In this study, RMA techniques were used to: (1) identify prawn feed marketing channels, (2) visit physical facilities such as feed markets, and (3) directly observe feed processing, transporting and market systems. A total of 24 market operators were interviewed, including feed traders, intermediaries and suppliers.

2.2.4 Key informant interviews

A key informant is someone with special knowledge on a particular topic. Key informants are expected to be able to answer questions about the knowledge and behaviour of others, and the operations of the broader systems (Elmendorf and Luloff, 2006). In this study, key informant interviews were conducted with school teachers, local leaders, government fisheries officers, researchers, policymakers, relevant non-government organizations (NGO) workers and project staff (e.g. Bangladesh Shrimp and Fish Foundation, Danida, Katalyst, WorldFish Center, Winrock International). During the study, 20 key informants were interviewed.

2.3 Data analysis

Data from questionnaire interviews were coded and entered into a Microsoft Excel database. A statistical package (SPSS – Statistical Package for Social Science, SPSS Inc., Chicago, IL, United States of America) was used to analyse the data. The results from the data analyses, in combination with qualitative information collected through different data collection methods were used to describe feed management practices for prawn farming in rice fields. An economic analysis was conducted to determine net returns. The analysis was based on farm-gate prices, and current local market prices for farm inputs. Values were expressed in US dollars (US$1 = BDT 68 in February 2010). Table 2 presents the assumptions and calculations that were used for calculating the various costs and returns.

TABLE 2
Assumptions and calculations used to determine production costs and returns

Total costs	**= variable costs + fixed costs**
Variable costs	= cost of seed, feed, fertilizer, labour (family and hired), harvesting and marketing, and miscellaneous
Fixed costs	= cost of depreciation + interest + land use cost
Depreciation costs	= [(purchase price – salvage value)/economic life]
Interest	= 15 percent annual interest rate on operating capital (seed, feed, fertilizer and labour)
Land use cost	= valuation of land at its rental price or lease
Gross revenue	= total production x farm-gate price
Net return	= gross revenue – total costs

3. RESULTS AND DISCUSSION

3.1 Prawn farming systems

3.1.1 Prawn-fish-rice farming

Freshwater prawn farming in rice fields was widespread throughout the study area (Figure 2). The majority of farmers produce prawns, fish, rice and dike crops. Prawns are produced for export markets while fish, rice and vegetables are produced for the local markets and household consumption (Figure 3). A variety of vegetables are grown on the dikes; these include potatoes, tomatoes, onions, mustard, yard long beans, spinach, peas, ladies fingers (okras) and sweet gourds. A range of short production cycle fruits such as banana, guava and papaya are also grown on the dikes. Although integrated prawn-fish-rice farming is an extensive[8] farming practice, many farmers use improved farming methods where the prawns are cultivated in improved-extensive[9] (30 percent) and semi-intensive[10] (20 percent) systems. In general, extensive farmers mainly use snail meat as a feed source for the prawns. In contrast, farm-made aquafeeds and industrially manufactured pelleted feeds are used by improved-extensive and semi-intensive farmers respectively. Due to a lack of resources, technical knowledge, and inadequate technical support, none of farmers use intensive farming techniques.

[8] Extensive production systems typically use slightly modified versions of traditional methods and are called low-density and low-input systems (Shang, Leung and Ling, 1998). Inputs can be classified as material inputs (seed, feed and fertilizer) and management inputs (labour).

[9] An improved-extensive method is a modification of the traditional extensive farming systems where farmers apply higher stocking rates, and increase feed and other inputs (fertilizer and labour). Inputs remain lower than those used in semi-intensive farming systems. This method is suitable for prawn and shrimp aquaculture in Bangladesh.

[10] Semi-intensive operations apply intermediate stocking levels and inputs. Feeding and pond fertilization is carried out on a regular basis (Shang, Leung and Ling, 1998).

There are two prawn farming systems that can be used in rice fields, *viz.* integrated and alternate systems (Table 3). The choice of farming system is dependent on the ecology of the area as well as biophysical resources (i.e. pond size, water depth, and financial ability of the farmers to buy seed, feed and fertilizer). While most farmers (>80 percent) practice integrated farming and cultivate the monsoon season *aman*[11] rice with prawns during June to October, a few alternate farmers avoid cultivating monsoon rice – this is due to the negative effects that rice cultivation can have on prawn growth. During the dry season between January and April, all farmers cultivate *boro*[12] rice on the central plateau of their rice fields. The alternate farmers suggested that the *aman* rice competed with the prawns for living space. Many Asian countries (e.g. China, Thailand and Viet Nam) promote prawn culture in rice fields as a form of Integrated Pest Management (IPM), and it has proved an effective way to increase the productivity of rice and prawns (Giap, Yi and Liu, 2005). Prawn culture with rice farming is ecologically sound with rice production improving as the prawns predate upon insects and improve soil fertility (Matteson, 2000). In addition, the rice fields provide planktonic, periphytic and benthic food sources to the fish (Mustow, 2002). Finally, shade from the rice plants helps to maintain favourable water temperatures for fish culture during the summer (Kunda *et al.*, 2008).

FIGURE 2
A typical prawn-fish-rice farm in southwest Bangladesh

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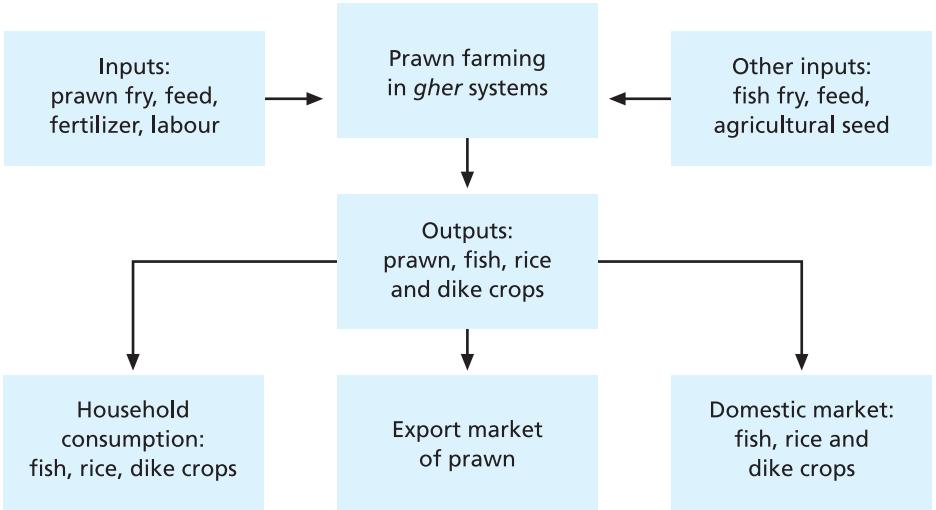
FIGURE 3
Prawn production processes in rice fields in gher systems



[11] *Aman* is the main rice crop in Bangladesh. It is planted during the monsoon season that begins in June. The crop is harvested in October-November.

[12] *Boro* rice is grown in the dry season from January to May. The crop is generally transplanted in January-February and harvested in April-May.

TABLE 3
Prawn farming systems in rice fields

Farming method	Extensive n = 30	Improved extensive n = 30	Semi intensive n = 30
Integrated farming (prawn-fish-aman rice in monsoon and boro rice in dry season)	27 (90%)	25 (83%)	24 (80%)
Alternate farming (prawn-fish in monsoon and boro rice in dry season)	3 (10%)	5 (17%)	6 (20%)

Note: n = sample size of prawn farmers.
Source: Field survey (2010).

3.1.2 Farm size

Management practices are important factors affecting productivity and profitability. Farm size appears to have an influence on productivity – an increase in farm size is generally associated with an increase in farming intensity, and hence productivity. In addition, farmers operating larger farms tend to have greater access to capital, managerial support, and the potential to operate and use resources efficiently. The survey revealed that the largest average farm size was 0.45 ha for semi-intensive farming systems, 0.28 ha for improved-extensive systems, and 0.19 ha for extensive farming systems. A significant difference ($p<0.05$, F-test) was found between the size of a farm and the farming system that was used. The principal water sources that supply prawn farms are rainfall, groundwater, and sometimes canal and river water.

According to Fan and Chan-Kang (2005), Asian farming is characterized by small farms, and small-scale farmers play an important role in providing food security and poverty alleviation. There is a positive relationship between farm size and labour productivity, and therefore income. In the study area, prawn farms average 0.31 ha compared with 0.60 ha for rice-only farms (Muir, 2003). Due to population increases, the average size of rice farms declined from 1.43 ha in 1961 to 0.87 ha in 1994, and is now just 0.60 ha (Rahman and Parkinson, 2007). In the past, prawn farms were also larger, and about two decades ago, they averaged 0.35 ha in Bagerhat district (Rutherford, 1994).

Farm size is also associated with cropping intensity (i.e. the total cropped area). The survey revealed that farmers using semi-intensive farming techniques attained higher cropping intensities of 191 percent, compared with 183 percent in improved-extensive, and 175 percent in extensive farming (the cropping intensities exceed 100 percent as the calculation takes into account those areas that are harvested more than once a year). In response to a growing population and demand for food, Bangladesh agriculture has generally increased cropping densities. In the study area, cropping intensity was found to be higher in the larger farms. This was attributed to farmer wealth, which was positively related to farm size and the ability to invest in farm inputs.

Saline water intrusion in coastal areas as a result of climate change is of serious concern to the farmers. However, it is likely that the issue can be resolved by adopting appropriate soil and water management practices, and introducing of salt tolerant rice varieties (Haque, 2006).

3.1.3 Postlarvae (PL) stocking and feeding

The peak season for prawn farming is between May to January. Prawn PL are stocked when they become available in May to June, and are primarily harvested between November and January; a culture period of around six to nine months. As hatchery produced PL are in limited supply, prawn culture remains dependent on the collection of wild PL. Farmers consider hatchery reared PL to be of a lower quality. The survival of wild-caught PL are reported to be much higher than that

those of hatchery produced PL. Although there are 81 freshwater prawn hatcheries in Bangladesh, only 38 (47 percent) are operational. These hatcheries produce around 100 million PL per annum, equating to 20 percent of the total demand (Ahmed and Troell, 2010). A paucity of technical knowledge, inadequate skilled manpower and insufficient supplies of wild broodstock are important factors that account for the low levels of hatchery production. Farmers estimate that around 15 to 20 percent of PL stocked are hatchery produced.

As opposed to stocking juveniles, farmers prefer to stock PL. This is due to their low price and availability in the local markets. The average stocking densities (average weight 0.02 g) were found to be 2.5 PL/m^2 in semi-intensive farming, 2.0 PL/m^2 in improved-extensive and 1.5 PL/m^2 in extensive systems. There was a significant difference ($p<0.05$, F-test) between the stocking rates applied to the different farming systems. Until recently, most farmers stocked PL directly into their grow-out ponds, and did not use nursery systems. However, to improve survival rates, most farmers have started to use net cages (*hapas*) as nurseries. In general, farmers rear PL for a period of four to six weeks at stocking rates of 50 to 100 PL/m^2.

Between the farming systems, there are differences in the management of the PL nursery production phase. With respect to the pre-stocking in semi-intensive farming systems, nursery cages are limed (200–250 kg/ha) and fertilized with cow dung (100–150 kg/ha), urea (20–35 kg/ha) and triple super phosphate (TSP: 25–50 kg/ha). Farmers use fertilizers to enhance natural productivity in the nursery cages[13]. However, due to the cost and the availability of capital, most improved-extensive farmers use lower levels of inorganic fertilizer and cow dung. Nevertheless, most nursery operators using the extensive farming systems apply cow dung and mustard oil cake a few days before stocking their PL.

All semi-intensive, and the majority of improved-extensive farmers, use formulated commercial feeds for PL rearing. The use of these feed results in higher survival and growth rates. In general, farmers apply feeds at four to six percent of body weight per day. Formulated prawn nursery feeds contain 35–42 percent protein. However, formulated commercial feeds are expensive, and many improved-extensive and most extensive farmers are unable to afford these feeds. Wheat flour is commonly used as an alternative by resource-poor farmers for PL rearing. In the first week of PL stocking, 50 g of wheat flour is applied per 1 000 PL; double this quantity is fed in the second week.

3.1.4 Fish stocking

Almost all farmers surveyed rear fish with their prawns. Fish are stocked at the same time as the prawns, but are harvested throughout the year. Farmers stocked Indian major carps, such as catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus cirrhosus*), and exotic carps such as silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and the common carp (*Cyprinus carpio*). In general, farmers do not stock specific ratios of the different carp species. The average size of fingerlings stocked varied from 5 to 7 cm (5–7 g). The highest average annual stocking density was found to be 5 112 fingerlings/ha in semi-intensive farming systems, followed by 4 365/ha in improved-extensive systems, and 3 571/ha in extensive systems. There was a significant difference ($p<0.05$) in the fish stocking rates between the different farming systems.

In addition to the carps, a number of small indigenous fish species (SIS) are cultured with the prawns. There are 260 species of freshwater fish in Bangladesh. Of these, 143 species (55 percent) have been classified as SIS (Mazid and Kohinoor,

[13] PL are omnivorous, feeding mainly on zooplankton. It is necessary to maintain adequate zooplankton densities in nursery cages.

2003). The most common SIS cultured with prawns are mola (*Amblypharyngodon mola*), dhela (*Osteobrama cotio*), kholisha (*Colisa fasciatus*), puti (*Puntius* sp.), tengra (*Mystus vittatus*), shing (*Heteropneustes fossilis*) and koi (*Anabas testudineus*). Among the SIS, mola contains more available vitamin A than any other edible freshwater fish in Bangladesh (Roos, Islam and Thilsted, 2003). SIS are also regarded as self-recruiting species that enter the rice fields from adjacent floodplains during the monsoon and reproduce in the inundated rice fields. The natural aggregation of SIS in rice fields has inspired prawn farmers to increase productivity. As SIS are not deliberately stocked in the prawn farms, the number of SIS cultured remains unknown. Nevertheless, it was suggested by the respondents that the average number of SIS varied from 500 to 1 000/ha.

3.1.5 Prawn feeding

Prawn farming is primarily dependent upon an adequate supply of quality feeds. In terms of increasing production, feed is one of the most important inputs. A major limiting factor to growth is feed intake, and as prawns are generally slow feeders, pellet stability is of primary importance to ensure adequate feed intake.

There is great potential to increase farm productivity through increased feed supply. Supplemental feeds are used for prawn farming in rice fields. A variety are used, including freshwater snails, farm-made aquafeeds and industrially manufactured pelleted feeds. In general, semi-intensive prawn farming is dependent on reliable sources of pelleted feeds, while extensive and improved-extensive farming primarily rely on snail meat and farm-made aquafeeds respectively. The highest average annual feeding rate was estimated at 1 627 kg/ha in semi-intensive farming systems, followed by improved-extensive (1 506 kg/ha) and extensive farming systems (1 454 kg/ha; Table 4). There was a significant difference ($p<0.05$) between the feeding rates applied to the different production systems.

3.1.6 Fertilization

All the farmers reported using fertilizers for grow-out production. Fertilizers stimulate the growth of natural feeds (e.g. phytoplankton, zooplankton, benthos and periphyton), thereby increasing prawn and fish yields. Prawn farmers use organic and inorganic fertilizers. The most widely used organic fertilizer is cow dung, which is relatively cheap and readily available in rural Bangladesh. The use of inorganic fertilizer is not widespread, and only a few of the more prosperous farmers can afford them. They use a mixture of chemical fertilizers including urea and TSP, which are usually used in combination with cow dung.

Semi-intensive farmers using pelleted feeds applied more fertilizers than the improved-extensive or extensive farmers (Table 4). Extensive farmers using snail meat as a feed source only applied organic fertilizer – mainly cow dung. The use of cow dung was attributed to a lack of technical expertise in terms of fertilizer application, and an inability to afford most expensive, alternative fertilizers. Farmers employing improved-extensive farming techniques using farm-made aquafeeds relied on both organic and inorganic fertilizers but, due to financial constraints, applied their fertilizers at lower rates than the semi-intensive farmers. There was a significant difference ($p<0.05$) between the fertilization rates used in the different farming systems.

TABLE 4
Inputs of integrated prawn-fish-rice farming in different production systems

Input	Extensive Mean ± SD	Improved-extensive Mean ± SD	Semi-intensive Mean ± SD
Farm size (ha)	0.19 ± 0.07	0.28 ± 0.11	0.45 ± 0.13
Stocking (number/ha/year)			
Prawn PL	15 431 ± 2 560	20 369 ± 3 632	24 752 ± 4 597
Fish fingerlings	3 571 ± 681	4 365 ± 729	5 112 ± 905
Feeding (kg/ha/year)	1 454 ± 517	1 506 ± 719	1 627 ± 931
Fertilization (kg/ha/year)			
Cow dung	1 447 ± 223	1 228 ± 207	1 196 ± 189
Urea	-	119 ± 33	286 ± 47
TSP	-	57 ± 19	172 ± 35
Labour* (man-days/ha/year)	121 ± 29	139 ± 41	152 ± 38

Notes: SD = standard deviation.
*A man-day was defined as 8 hours of work.
Source: Field survey (2010).

3.1.7 Labour input

Labour is required for farm construction, stocking, feeding, fertilization, harvesting and marketing. The sources of labour that were reported in the survey included family labour[14], for which no payment was made, and hired labour, for which farmers had to pay in cash. The hired labour can be further classified into casual labour and labour hired on an annual basis. To determine the value of unpaid family labour, the opportunity cost[15] was calculated. It was difficult to estimate the amount of family labour involved in prawn farming, but respondents indicated that it contributed 60 – 70 percent of the total labour requirement of the farms. According to the survey, the highest labour requirements accrued to semi-intensive farming systems, followed by improved-extensive and extensive farming systems (Table 4). There was a significant difference ($p<0.05$) between the labour inputs between different farming systems.

3.2 Snail meat as a feed source in prawn culture

3.2.1 Snail harvesting

The use of snail meat as a prawn feed is widespread in southwest Bangladesh. There are about 450 species of snails in Bangladesh of which 300 inhabit the coastal belt (Gain, 1998). However, only the freshwater snail (*Pila globosa*) is traditionally used as a prawn feed. The snail is a valuable aquatic resource whose preferred habitat is low-lying marshland. This snail is widely distributed throughout the wetlands and rivers of Bangladesh. They can be found gliding upside down beneath the surface film of the water body in which they live (Baby *et al.*, 2010). They primarily feed on the leaves of aquatic plants, and their removal can result in increased growth of aquatic macrophytes, possibly reducing light penetration and photosynthesis, and ultimately leading to the eutrophication of water bodies (Gain, 1998).

[14] Family labour was difficult to quantify as the farmers were often unable to differentiate the use of family labour for different purposes.
[15] Opportunity costs refer to the costs associated with giving up an opportunity. The opportunity cost creates an implicit price relationship between competing alternatives. The opportunity cost of a human labour is its value as its best alternative use.

Snail populations are reported to have declined significantly in Bagerhat district. This is attributed to excessive harvesting during the monsoon period, which coincides with the peak reproductive season of the species. Snails are also harvested from wetlands and rivers in neighbouring districts including Gopalgonj, Faridpur and Madaripur. A large number of impoverished rural people live in the wetland areas of these districts where fishing and snail harvesting are the main economic activities. A wide variety of people including women and children are involved in snail harvesting, and the supply of snails has generated many employment opportunities in harvesting, processing, transport and marketing.

The practice of collecting snails to supply the prawn culture industry was initiated in 1992 (Ahmed, 2001). The peak season for snail harvesting is from June to October. On average, snail collectors are engaged for five hours (range: three to seven hours) a day. During the morning (06.00–10.00 hours) and late afternoon (14.00–17.00 hours), the snails float on submerged vegetation as well as on the surface of the water. During hot weather when there is strong sunshine, and during rainfall, the snails will drop from the surface and fall to the bottom of the water column. The snails are collected using a triangular concave mesh net attached to a short pole which is used to scoop the snails off the surface. Hundreds of small boats are involved in snail harvesting. Each boat is operated by a single harvester. A snail collector harvests an average of 20 kg of snails a day (range: 10–30 kg per day). The collected snails are stored in the boats, and transported to collection points.

3.2.2 Transporting snails

A large number of impoverished rural people are involved in transporting snails from the wetland areas to the prawn farming areas in Bagerhat district. Local suppliers carry them to Bagerhat district using trawlers, trucks or boats; these journeys, depending on the distance and the mode of transport, take between two and four hours. The snails are sold to traders. A number of people are employed by the suppliers as day labourers for loading and unloading. Rickshaws and vans are also commonly used to transport the snails to the prawn farms. To take advantage of the cooler temperatures, the snails are transported to the prawn farms at night or in the early morning hours. Nevertheless, due to hot temperatures and rough handling, some snails are spoiled during transit.

3.2.3 Processing snail meat

Prior to feeding to the prawns, the snails are shucked and the meat is removed from the shells. The snail traders employ adults and children as day labourers for this purpose (Figure 4). Processing involves breaking the operculum and removing the meat from the shells with a small curved knife. A woman can process five to six baskets of snails a day. Each basket contains 20 kg of snails and provides 8–10 kg of snail meat. To maintain meat quality, the snails must be processed within 24 hours of harvesting. Temperatures in excess of 30 °C increase the potential for spoilage.

FIGURE 4
Shucking the snails and removing the meat

COURTESY OF FAO/NESAR AHMED.

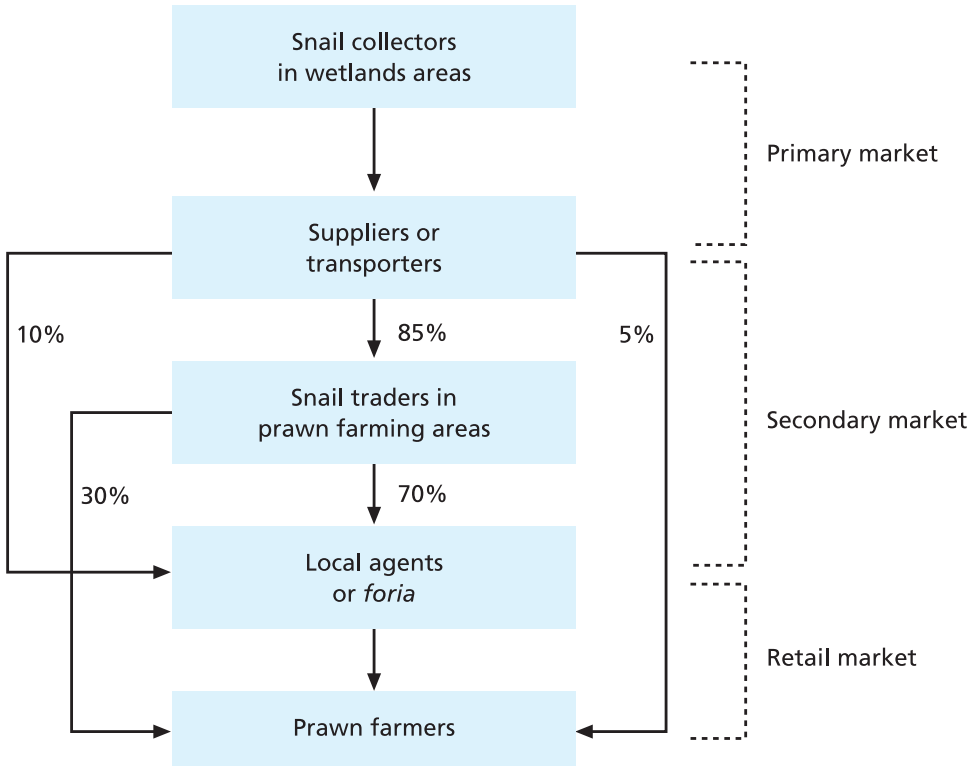
3.2.4 Use of snail shells

The use of snail meat as an agricultural feed generates large volumes of shells. The shells are generally discarded by the roadside, in canals, and other places away from the processing locations. In recent years, people have begun to collect and process the shells to produce lime, and the shells are now increasingly used in the local lime factories. In Bagerhat district, they are processed as poultry and/or fish feed supplements, and as a fertilizer for homestead gardening. They are also used as a duck feed. According to White *et al.* (2007), snail shells provide a rich source of calcium carbonate, which can be used to enrich the soil, and as a supplement in bird feeds.

3.2.5 Snail trading

The traditional snail marketing system plays a vital role in connecting the farmers and harvesters, and significantly contributes to the value adding process. The value chain from harvesters to farmers encompasses primary, secondary and retail markets, and involves suppliers, traders and local agents (Figure 5). The peak season for snail trading is between June and October, and corresponds to the period when the farmers cultivate prawns. During this period, the snail traders make their primary living by buying and selling snails. Snail trading is a seasonal business and traders engage in trading for six to ten hours a day. The rest of the time they are involved in prawn farming, PL trading and prawn marketing. In the study area, 15–20 snail traders were found to be operating in a single market. During the season, the traders sell an average of 90 kg snail meat per day (range: 45 to 130 kg). Traders sell their snails or snail meat either directly or *via* local agents to the prawn farmers. According to the snail traders, the average price of snail meat in 2010 was US$0.15/kg.

FIGURE 5
The freshwater snail supply chain from harvesters to prawn farmers



3.2.6 Feeding snail meat

Snail meat is mainly used by resource-poor farmers using extensive farming techniques. The survey revealed that an average 1 454 kg/ha/year of snail meat is used in these extensive systems. Almost all the farmers reported using broadcast feeding. It was evident that farmers had little understanding of how to improve their feed management practices. In general, chopped snail meat is fed in the morning and/or the evening (Figure 6). According to the survey, the vast majority of respondents (70 percent) fed the meat once a day; only 10 percent fed twice a day (Table 5). Twenty percent of respondents used feeds at irregular intervals – two to three times per week. Irregular feeding was attributed to inadequate supplies. The supply of snail meat is often irregular, and therefore farmers often supplement their use with farm-made feeds that are prepared by mixing cooked rice, rice bran and wheat flour. The farmers reported that the production of prawns is higher and production costs lower when snails are used as opposed to farm-made feeds.

FIGURE 6
Prepared snail meat

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TABLE 5
Feeding frequencies applied to different feed types

Feeding frequency	Snail meat n = 30	Farm-made feed n = 30	Manufactured aquafeed n = 30
Once daily	21 (70%)	18 (60%)	16 (53%)
More than once daily	3 (10%)	7 (23%)	14 (47%)
Irregular (2–3 times/week)	6 (20%)	5 (17%)	-

Note: n = sample size of farmers.
Source: Field survey (2010).

3.3 Farm-made aquafeeds

3.3.1 Feed ingredients

A variety of ingredients are used in the production of farm-made aquafeeds. In general, farmers use a mixture of rice bran, mustard oil cake, fishmeal, oyster shell, salt and vitamins. The feed is usually formulated to contain 40 percent rice bran, 30 percent mustard oil cake, 25 percent fishmeal, and 5 percent minerals and vitamins (oyster shell, salt and vitamins). Although many ingredients (i.e. rice bran, mustard oil cake, oyster

shell) are on-farm agricultural by-products, it was estimated that about 60 to 70 percent of the feed ingredients used in the production of farm-made aquafeeds had to be purchased. Farmers mainly use rickshaws, vans and motorized vehicles to transport the feed ingredients from the local markets. Despite the importance of maintaining the quality of feed ingredients during transportation, storage and processing, it was evident that farmers have little knowledge on how best to store and handle their feed ingredients. Most farmers using farm-made aquafeeds prefer to purchase small amounts of ingredients and not store their feeds – this purchasing behaviour was attributed to a lack of financial means to purchase in bulk, and inadequate storage facilities.

The majority of farmers (65 percent) irregularly use machines to mix their feed ingredients (Figure 7). The remaining farmers (35 percent) do so manually (Figure 8). Farmers produce the pellets using their own machines, or have the local feed mills produce the pellets for them (Figure 9). The feed manufactures produce feeds using hauler machines (22 horsepower). Farmers transport their feed ingredients to the feed mills to manufacture the pellets, and pay for the manufacturing process. However, many farmers also reported mixing their own feed ingredients manually, and thereby reducing their feed manufacturing costs.

FIGURE 7
A machine for preparing farm-made aquafeeds

COURTESY OF FAO/NESAR AHMED.

FIGURE 8
Manually mixing farm-made aquafeeds

COURTESY OF FAO/NESAR AHMED.

FIGURE 9
Drying of farm-made aquafeeds

COURTESY OF FAO/NESAR AHMED.

3.3.2 Rice bran

In Bangladesh, the most commonly used aquaculture feed is rice bran, a by-product of rice – the main crop of the country. There are three types of rice crops in Bangladesh: *aman*, *aus* and *boro*. While *aman* rice accounts for 50 percent of the total rice crop area, *aus* and *boro* account for 27 percent and 23 percent respectively. In 2008/09, over 29 million tonnes of rice was produced from about 10.8 million ha of rice fields (BRKB, 2010). The three types of rice provide a year round supply of rice bran which accounts for five percent (1.45 million tonnes) of the total rice yield (Barman and Karim, 2007). The average annual requirement for rice bran used in farm-made aquafeeds is estimated at 602 kg/ha. About 30–40 percent of rice bran supply is normally derived from on-farm rice production, and the remainder is purchased. The average price of rice bran was estimated to be US$0.15/kg. Considering the importance of rice bran in prawn feeds, it is necessary to maintain its quality during production, storage and transportation. The quality of rice bran depends on nutrient value, freshness, fineness, storage conditions and the duration of storage. In general, rice bran produced in automated rice mills has a higher nutrient value than that produced in the rural husking mills (Barman and Karim, 2007). The proximate composition of rice bran varies greatly, and is presented in Table 6.

TABLE 6
Proximate composition of farm-made aquafeed ingredients used in prawn farming (percent dry weight basis)

Feed composition	Rice bran	Mustard oil cake	Fishmeal
Crude protein	9.8–17	35–40	40–56
Crude lipid	7.7–22.4	19.8	16–20
Crude fibre	5.7–20.9	14.9	2–6
Ash	7.1–20.6	6.6	21.3
Nitrogen-free extract (NFE)	40–41	29.0	0.7

Source: Barman and Karim (2007).

3.3.3 Mustard oil cake

Mustard oil cake is widely used as a aquafeed ingredient in Bangladesh, and is one of the most important ingredients in prawn feeds. It is a by-product of the production of mustard seed oil. Annual oilseed production in Bangladesh is 267 000 tonnes, of which 72 percent (192 240 tonnes) accrues to mustard oilseed (Basak, Pandit and Khurram, 2007). Approximately 48 060 tonnes of mustard oil cake is produced per annum. The overall demand for mustard oil cake has increased as the national aquaculture sector has expanded. The survey revealed that an average of 452 kg/ha/year of mustard oil cake was used to prepare farm-made prawn aquafeeds. The vast majority of farmers (90 percent) reported purchasing this ingredient. The average price of mustard oil cake was estimated to be US$0.21/kg. Its quality depends on oil production systems, freshness, fineness, storage conditions and the storage duration. Mustard oil cake is rich in protein (35–40 percent). The proximate composition is presented in Table 6.

3.3.4 Fishmeal

Fishmeal is widely used as a protein source in aquafeeds, and is recognized by the prawn farmers as a high-quality, highly digestible feed ingredient. In Bangladesh fishmeal is generally produced from trash fish/low-value fish. Fishmeal can be manufactured from small pelagic marine fish that are not used for human consumption. It can also be made from fisheries by-catch, and seafood processing plant waste. Fishmeal quality varies according to the quality and composition of the source fish

that are used in the manufacturing process. The Bangladesh Fisheries Development Cooperation has four fishmeal production plants with a combined production capacity of eight tonnes per day. Around four to five tonnes of fish are required to produce one tonne of dry fishmeal (Miles and Chapman, 2006). The survey revealed that on average, 377 kg/ha/year of fishmeal was used by farmers in their farm-made aquafeeds. Almost all respondents reported buying fishmeal from the local market. The average price of fishmeal was reported to be US$0.32/kg. Typical composition is shown in Table 6.

3.3.5 Other ingredients

In addition to rice bran, mustard oil cake and fishmeal, other ingredients, including oyster shell, vitamin premix and salt, are used by prawn farmers to prepare farm-made aquafeeds. The survey revealed that all these ingredients were purchased from the local market. Oyster shell contains a high proportion of calcium carbonate, and is used as a supplement in prawn feeds. A number of vitamin premixes are used – all include vitamins A, B, C, D, E and K. Vitamin premixes have beneficial effects on prawn growth, disease resistance, immune system functioning, and their use reduces stress (Mitra, Mukhopadhyay and Chattopadhyay, 2005). Iodized salt is also added to farm-made aquafeeds. The average price of iodized salt was reported to be US$0.29/kg, which is significantly higher than oyster shell (US$0.07/kg). The price of vitamin premixes range from US$0.65–1.2/g.

3.3.6 Feeding practices

Sixty percent of respondents fed farm-made feeds once a day, 23 percent fed twice a day, and 17 percent fed two to three times a week (Table 5). Based on these feeding frequencies, there was considerable variation in the quantity of feed used by the different farms surveyed. On average, the annual feeding rate of farm-made aquafeeds was estimated to be 1 506 kg per hectare. As the feed that is used is a slow sinking pelleted feed, it is applied by broadcast methods. Overall, the use of feed has increased in recent years, and as such, there has been a concomitant increase in the productivity of the systems. However, it was evident that there was considerable variation between the farmers in terms of the quantity of feed that they used. This variation was attributed to the availability of feed ingredients and farmer's ability to purchase feeds. Although most farmers indicated that they would like to use more feeds and increase productivity, many are unable to invest in additional feeds. The average price of farm-made aquafeeds was calculated as US$0.35/kg.

3.4 Commercially manufactured aquafeeds

3.4.1 The feed industry

The survey revealed that there are 44 registered commercial feed manufacturers in Bangladesh that produce poultry and aquaculture feeds, including those for prawns and shrimps. In reality this figure is likely to be larger as there are many unregistered feed manufacturers. While almost all the feed production facilities produce poultry and fish feed, only 25–30 percent produce prawn and shrimp feeds (Chisty, 2009). There are many commercial prawn feed manufacturers in Bangladesh, which use machinery imported from China, Germany, India, Thailand and the United States of America. They are located throughout the country and, *inter alia*, can be found in Chittagong, Dhaka, Gazipur and Khulna regions. Feed production rates vary between 5 and 25 tonnes/hour, depending on capacity and the available manpower. Bismillah Feed Mills have the major market share for prawn feeds, followed by Quality Feed Ltd, Sunny Feed Ltd and Niribili Feeds Ltd (Table 7). Farmers select their feeds according to a number of factors including quality, price, availability and the technical support supplied by the feed companies.

TABLE 7
Commercial prawn feed production capacity (2009)

Feed company	Production (tonnes/year)
Bismillah Feed Mill	20 000
CP Feed	1 200
Niribili Feed Ltd.	3 000
Quality Feed Ltd.	7 000
Saudi Bangla Fish Feed Ltd.	500
Spectra Hexa Feeds Ltd.	500
Sunny Feed Ltd.	5 000

Source: Field Survey (2010).

3.4.2 Feed ingredients

In general, feed manufacturers use similar ingredients to produce prawn feeds. These include fishmeal, mustard oil cake, de-fatted rice bran, rice polish, wheat flour, maize, meat and bone meal, soybean oil, calcium phosphate, sesame oil cake, salt and vitamin premixes. Although similar ingredients are used by the various aquafeed manufacturers, their formulations differ. The majority of feed ingredients are sourced locally; however some, including meat and bone meal and defatted soybean meal are imported.

The use of food additives, including anti-fungal, mould inhibitors and antibiotics, is commonplace. Nitrofurans and chloramphenicol are two types of antibiotic that are used to treat bacterial infections. Due to public health concerns, these antibiotics have been banned for use in animal production systems in many countries e.g. Australia, the European Union (EU), Canada and the United States of America. Almost all feed manufacturers in the survey denied using banned antibiotics. However, banned antibiotics have been found in many prawn feeds in the country (Islam, Khan and Reza, 2009). It is possible that these banned chemicals may be being introduced into the feeds by incorporating adulterated feed ingredients that contain the banned substances, possibly from imported ingredients such as meat, bone meal and fishmeal (Chisty, 2009). Carry-over contamination from batches of other animal feeds manufactured in the same equipment may also be responsible (M. New, personal communication, 2012).

3.4.3 Types of feed produced

The majority of prawn feed manufacturers produce three types of prawn feeds, *viz.* starter feeds for use in the nursery; grower feeds for juveniles and adult prawns; and finisher feeds for adult prawns. Most feed manufacturers use different trade names, and they usually use two or more brand names as a component of their marketing strategies. The nursery feeds are usually sold in 1 kg, 5 kg and 20 kg bags. Starter, grower and finisher feeds are sold in 25 kg bags. The average feed price was US$0.59/kg and, depending on the type and quality, varied between US$0.44 and US$1.03/kg. The quality of feed depends on the proximate composition and feed manufacturing process. The proximate composition of the different prawn feeds that are available in the market varies considerably; the composition of a selected example of each feed type is shown in Table 8. Nutritional information including the moisture, protein, lipid, fibre and energy contents is provided on the feed bags.

TABLE 8
The proximate composition of selected manufactured prawn feeds (percent dry matter basis)

Proximate composition	Starter*	Grower**	Finisher***
Crude protein	38	36	35
Crude lipid	6	4	4
Crude fibre	4	5	6
Ash	13	16	16
Moisture	10	11	12
Nitrogen-free extract	29	28	27

Notes: Feed brands - * Mega feed, ** Saudi-Bangla Fish Feed, *** Mega feed.

Source: Field survey (2010).

3.4.4 Transport of feed

The majority of feed manufacturers do not have their own vehicles, and depend on hired vehicles for feed transportation, but a few of the foreign feed manufacturing companies have a limited number of vehicles for this purpose. In general, trucks and pickups are used to transport feed from the manufacturers to the dealers. As dealers directly supply the feed to the sub-dealers, they operate storage facilities and have supply contracts with the latter. Pickups and vans are commonly used to transport feed from the dealers to the sub-dealers. Finally, the farmers transport the feed from the sub-dealers using vans, rickshaws, or by foot. Usually the cost of transporting the feed from the manufacturers to dealers is borne by the dealers. Similarly, the cost of feed transportation from the dealers to sub-dealers is borne by the sub-dealers. Ultimately, the farmers bear the cost of transporting the feed to the farm.

3.4.5 Feed marketing

Almost all prawn feeds manufactured in Bangladesh are produced for domestic prawn farming. A considerable number of people are employed in the feed market chain as suppliers, transporters, traders, intermediaries and day labourers. The feed market system is less competitive but plays a vital role in connecting the manufacturers to the farmers. In order to improve feed sales, some feed companies employ technical personnel to assist and advise both dealers and farmers.

The feed value chain from manufacturers to farmers involves primary, secondary and retail markets, suppliers, dealers and sub-dealers (Figure 10). With a few exceptions, manufacturers do not directly communicate with farmers.

FIGURE10
Feed supply chain from feed manufactures to prawn farmers

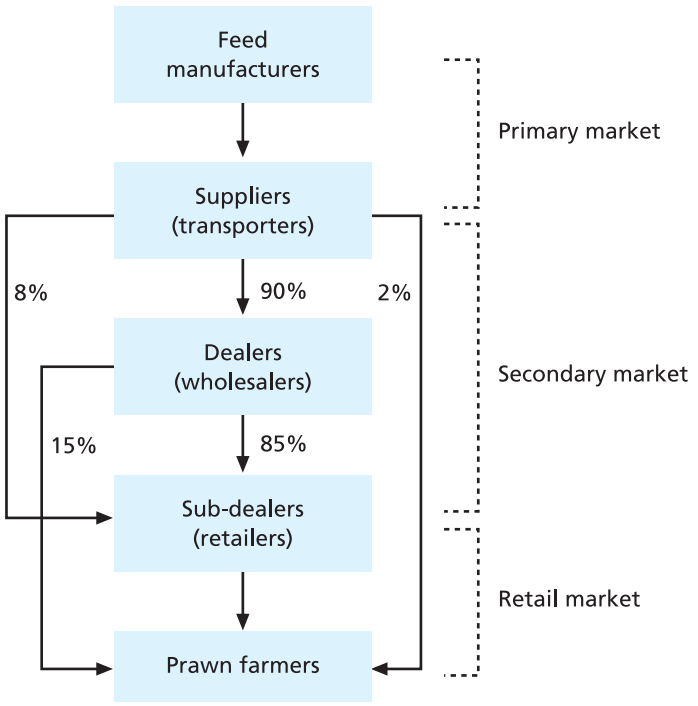

FIGURE 11
The store of a local dealer selling manufactured pelleted feeds

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The communication networks between the market actors is generally good and is assisted by the use of mobile phones. Suppliers include intermediary traders who supply feed from the manufacturers to the dealers (Figure 11). In general, the suppliers are tied to a limited number of dealers. Similarly, a limited number of sub-dealers are associated with the dealers. Finally, the sub-dealers sell feed to the farmers for cash or on credit. It was reported that most feed is sold on credit.

FIGURE 12
Commercially manufactured pelleted feeds

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3.4.6 Feeding practices

Almost all industrially manufactured prawn feeds (Figure 12) are slow sinking, and farmers feed using broadcast methods. The survey revealed that 53 percent of the farmers fed once a day, with the remaining 47 percent feeding twice a day. Typical feeding schedules for use with starter, grower and finisher feeds are presented in Table 9. When the PL become juveniles, farmers apply starter feeds at the rate seven to ten percent of body weight per day for a period of 4 weeks. Grower feeds are used five to six percent of body weight per day for 5–24 weeks. Finally, finisher feeds are used at the rate of three to four percent of body weight per day for the last four to six weeks of the production cycle. On average, annual feeding rates were estimated at 1 627 kg/ha across all feeding classes.

TABLE 9
Feeding schedules for commercially manufactured pelleted feeds

Feed type	Prawn size (g)	Feeding duration	Feeding rate (% body weight/day)
Starter	4–7	First 4 weeks	7–10
Grower	8–20	5–24 weeks	5–6
Finisher	>20	Last 4–6 weeks	3–4

Source: Field survey (2010).

3.5 Constraints to feed management

The farmers surveyed reported a number of feed and feed management issues. These included the high price of feed, an inadequate supply of feed and feed ingredients, poor feed quality, procurement problems, the decomposition of feed, water pollution due to excessive feed use, and a poor knowledge of feed management practices. The following section describes the constraints to feed management in the different culture systems that are currently in use.

3.5.1 Snail meat

Snail meat is a non-conventional but important feed source for prawn farming. Forty three percent of respondents using snail meat identified an inadequate supply as the key production constraint (Table 10). During the peak farming season (June to October) farmers reported that they required 30–40 kg/ha of snail meat per day. However, the supply of snails is irregular and farmers reported only having access to 10–20 kg/ha/day at some times. The high price of snail meat is also a key constraint for resource-poor farmers, and in recent years the price of snail meat has increased significantly. In 2010, the average price of snail meat paid to the harvesters was US$0.07/kg. In contrast, the prawn farmers paid an average price of US$0.15/kg. The majority of farmers reported that over a decade ago, snail meat was sold at an average of US$0.04/kg.

Thirteen percent of the farmers using snail meat indicated that procuring this commodity was their most important feed management constraint. Despite recent and substantial improvements to the road infrastructure, access to remote areas remains problematic, particularly in the monsoon season. Transport time can be considerable, resulting in the snails degrading during transit. Indeed, ten percent of respondents identified the decomposition of snail meat as a constraint. The use of decomposed snail meat results in poor water quality, and is believed to be a key factor causing disease. Only seven percent of farmers reported an inadequate knowledge on feed management practices to be the most important constraint.

TABLE 10
Key constraints to feed management

Key constraint	Snail meat n = 30	Farm-made feed n = 30	Commercial feed n = 30
High price	6 (20%)	14 (47%)	16 (53%)
Inadequate supply	13 (43%)	6 (20%)	2 (7%)
Procurement problem	4 (13%)	4 (13%)	4 (13%)
Poor quality	3 (10%)	3 (10%)	5 (17%)
Water pollution by feed	2 (7%)	2 (7%)	1 (3%)
Inadequate knowledge on feeding	2 (7%)	1 (3%)	2 (7%)

Note: n = sample size of farmers.

Source: Field survey (2010).

3.5.2 Farm-made aquafeeds

Forty seven percent of the farmers using farm-made feeds identified high feed prices as the most important issue affecting their feed use. The price of feed ingredients, including rice bran, mustard oil cake, fishmeal, oyster shell, vitamin and salt has increased significantly as prawn farming has become widespread throughout southwest Bangladesh. Moreover, the supply of feed ingredients is often inadequate, and in this regard, 20 percent of these farmers identified feed ingredient availability as a constraint. Due to salt water intrusion, the production of rice is insufficient in coastal Bangladesh, and the production of mustard oil seed is also limited in the coastal area. As such,

the availability of rice bran and mustard oil cake in the local markets is dependant on supplies from other parts of the country. This results in high transport costs and increased prices. Due to the proximity to the coastal areas, the supply of fishmeal and oyster shell is adequate. Nevertheless, 13 percent of the farmers identified feed ingredient procurement as the major issue. This was due to the rural nature of many farms, and the concomitant long distances to markets.

Ten percent of the farmers using farm-made feeds identified poor quality of feed ingredients as the major constraint to their operations. To resolve the issue, these farmers reported applying more feed to obtain the desired levels of growth. Overfeeding often leads to water pollution, which can manifest itself in low levels of production. The number of respondents identifying feed related water quality issues and an inadequate knowledge of feeding practices as the key constraint was seven and three percent respectively.

3.5.3 Commercially manufactured pelleted feeds

The majority of the respondents (53 percent) reported that high feed prices was the single most important constraint regarding their use of commercially manufactured pelleted feeds. Although wealthier farmers use these feeds, a major issue for farmers is a shortage of operating capital to purchase them. There are many commercial feed producers in Bangladesh and they reported that the price of industrial feeds has increased significantly as a result of increased manufacturing costs.

Despite the high feed prices, many farmers reported that they were not satisfied with the quality of the feeds that were available. Indeed, 17 percent of the farmers identified poor feed quality as the major constraint to their use. The use of feed additives including fungicides, mould inhibitors and antibiotics are common (Islam, Khan and Reza, 2009). Banned antibiotics including nitrofuran have been found in prawns, the source of which is thought to come from contaminated feeds. During May to December 2009, the Bangladesh Frozen Foods Exporters Association (BFFEA) imposed a ban of prawn exports to remove the antibiotic nitrofuran, which had been detected by EU importers. The ban was lifted after the BFFEA confirmed that prawns produced in Bangladesh no longer contained nitrofuran (Financial Express, 2010). The EU team suggested that the feed industry and processing plants should be brought under governmental regulation, and that an awareness campaign on antibiotic use was initiated at farm level. With this mind, the government has recently passed new feed legislation to regulate fish and animal feed manufacturers.

Feed management and a poor understanding of the means of determining appropriate ration sizes was identified as the major constraint by seven percent of the farmers. Although many feed manufacturers employ technical personnel to provide technical assistance in terms of optimizing feed management practices, many farmers still had a poor understanding of these practices, resulting in overfeeding, and concomitant water quality issues. Three percent of farmers reported feed-derived water pollution as their most important production constraint.

3.6 Productivity

3.6.1 Prawn production

The highest average annual yields of prawns (Figure 13) were reported from semi-intensive farming systems (718 kg/ha), followed by improved-extensive (489 kg/ha) and extensive systems (351 kg/ha; Table 11). A number of factors affect on-farm growth rates and productivity. These include farm size, inputs (seed, feed and fertilizer), feed quality, water quality, and farm management. As a result of using higher inputs and using commercially manufactured pelleted feeds, prawn yields were highest under the semi-intensive culture conditions. The lower prawn yields attained in the extensive farming systems were attributed

to lower inputs and the use of snail meat as a feed source.

The highest average economic feed conversion ratio[16] (FCR) was recorded in the extensive farming system (FCR: 4.14:1), followed by the improved-extensive system (FCR: 3.08:1), and the semi-intensive farming system (FCR: 2.27:1; Table 11). There was a significant difference ($p<0.05$) between the FCR attained in the different farming systems.

FIGURE 13
Harvested prawns for the international market

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TABLE 11
Productivity of prawn, fish and rice in different farming categories

Productivity	Extensive Mean ± SD	Improved-extensive Mean ± SD	Semi-intensive Mean ± SD
Feeding (kg/ha/year)	1 454 ± 517	1 506 ± 719	1 627± 931
Productivity (kg/ha/year)			
Prawn	351 ± 56	489 ± 71	718 ± 93
Fish	526 ± 68	824 ± 95	1 173 ± 124
Rice	2 453 ± 529	2 527 ± 758	2 491 ± 629
Feed conversion ratio (FCR)*	4.14:1 ± 0.78	3.08:1 ± 0.62	2.27:1 ± 0.55

*FCR is only calculated for the prawns because farmers provided supplementary feed specifically for the prawns. However, as fish also consume both farm-made and commercially manufactured pelleted feeds, the FCR may not be accurate in improved-extensive and semi-intensive systems. Nevertheless, the FCR is more likely to be accurate in extensive farming as the fish species stocked do not eat snail meat.

Source: Field survey (2010).

Larger prawns were harvested in semi-intensive farming systems. This finding was probably due to the improved nutrition that these animals were receiving from the commercially manufactured feeds. Conversely, smaller prawns were harvested in extensive farming. Farmers using improved-extensive systems and farm-made aquafeeds obtained medium-sized prawns. The effect of feed type and the size of prawns at harvest is presented in Table 12. According to the survey, the average harvest size was found to be 70 g in the semi-intensive system, 60 g in the improved-extensive system and 45 g in the extensive system.

[16] Biological FCR is the net amount of feed used to produce one kilogramme of fish. The economic FCR takes into consideration all the feed used and the effects of feed losses and mortalities (Tveteras, 2000). This study calculated the economic FCR.

TABLE 12
Grade, harvest size prawn and their production share in different farming practices

Grade*	No. of head-on prawns/kg	Average weight (g)	Product share (%) in farming category		
			Extensive	Improved-extensive	Semi-intensive
5	5 or less	200	1	3	5
10	6–10	125	4	7	10
20	11–20	70	30	35	40
30	21–30	40	40	35	30
50	31–50	25	25	20	15

*Bangladesh grading system.
Source: Field survey (2010).

3.6.2 Fish yields

Average annual fish yields varied from 526 kg/ha in the extensive systems to 824 kg/ha in the improved-extensive systems, and 1 173 kg/ha in the semi-intensive systems (Table 11). The size of fish at stocking, the culture period, and the size at which the fish were harvested influenced yields. Moreover, fish yields were also dependent on environmental and culture conditions. Amongst others, these included water quality, culture species, stocking density, and feed and fertilizer inputs. It was assumed that in terms of using farm-made aquafeeds and commercially manufactured pelleted feeds, the fish consume a portion of the feed that is provided. However, as carps are herbivorous, they were unlikely to eat the snail meat that was provided in the extensive farming systems. Nevertheless, fish farming in rice fields is primarily dependent on natural feeds (e.g. phytoplankton, zooplankton, periphyton and benthos). With respect to increasing fish productivity, farmers indicated that they required increased supplies of quality fry. Furthermore, production could be increased by increasing stocking densities and supplementary feeding and fertilization.

3.6.3 Rice yield

The highest average annual rice yields were achieved in the improved-extensive farming system (2 527 kg/ha), followed by the semi-intensive (2 491 kg/ha), and extensive (2 453 kg/ha) farming systems (Table 11). Measures of rice productivity included the area of canal and water devoted to aquaculture, and thus, actual yields per hectare are likely to be 25–30 percent higher than those reported. Nevertheless, rice productivity in these systems is significantly lower than in other parts of the country where an average of over 4 000 kg/ha per crop is the norm (BRKB, 2010). In the study area, total rice production has probably decreased as a result of the widespread conversion of rice fields into prawn farms. In addition, climate change, including floods and drought, is of grave concern in coastal Bangladesh. Many farmers reported that soil and water salinity have already increased substantially in prawn farms as a result of flooding. The farmers attribute these changes to climate change.

3.7 The economics of the farming systems

An economic analysis of the three production systems, comprising a comparison of production costs, cost structures and production efficiencies was undertaken.

3.7.1 Variable costs

Variable costs are those associated with the cost of seed, feed, fertilizer, labour, rice production and other miscellaneous items such as electricity, lime and marketing. The average annual variable costs of prawn farming (excluding dike cropping) varied

from US$1 082/ha in the extensive farming systems to US$1 627/ha in the improved-extensive systems, and US$2 314/ha in the semi-intensive farming systems (Table 13). Variable costs varied from 74 percent of the total costs in the extensive farming systems, to 78 percent in the improved-extensive farming systems, and 81 percent in the semi-intensive farming systems. Seed and feed are the two highest variable costs in prawn production. The average annual cost of seed in extensive, improved-extensive and semi-intensive farming was calculated to be 35 percent, 32 percent and 28 percent of the total variable costs, respectively. Feed costs comprised the second highest operational cost in extensive (15 percent) and improved-extensive (25 percent) farming, and constituted the highest operational cost in semi-intensive farming (33 percent of total variable costs). Considerable variation was also observed among other variable costs.

TABLE 13
Average production costs and returns (US$/ha/year) of different prawn farming systems

Cost and return	Farming system		
	Extensive	Improved-extensive	Semi-intensive
Variable costs			
Seed (prawn and fish)	506 (35%)	663 (32%)	803 (28%)
Feed	218 (15%)	527 (25%)	959 (33%)
Fertilizer	29 (2%)	60 (3%)	128 (5%)
Labour (family and hired)	178 (12%)	204 (10%)	224 (8%)
Rice cultivation	127 (9%)	138 (6%)	153 (5%)
Miscellaneous	24 (1%)	35 (2%)	47 (2%)
Total variable costs (TVC)	1 082 (74%)	1 627 (78%)	2 314 (81%)
Fixed costs			
Depreciation[1]	101 (7%)	113 (5%)	125 (4%)
Interest[2]	116 (8%)	181 (9%)	262 (9%)
Land use cost[3]	158 (11%)	167 (8%)	174 (6%)
Total fixed costs (TFC)	375 (26%)	461 (22%)	561 (19%)
Total costs (TC = TVC + TFC)	1 457 (100%)	2 088 (100%)	2 875 (100%)
Gross revenue[4]			
Prawn	1 418 (56%)	2 078 (59%)	3 231 (64%)
Fish	542 (21%)	849 (24%)	1 208 (24%)
Rice (including rice straw)	589 (23%)	606 (17%)	598 (12%)
Total gross revenue (GR)	2 549 (100%)	3 533 (100%)	5 037 (100%)
Net return (NR = GR – TC)	1 092	1 445	2 162
Benefit-cost ratio (BCR) = GR/TC	1.74	1.69	1.75

Notes: Parentheses indicate the percentage of total costs
[1](purchase price - salvage value)/economic life
[2]Interest on operating capital or loan was charged at the rate of 15 percent per annum (this calculation was applied to the 9 months of culture period)
[3]Valuation of land at its rental or lease price
[4]Productivity (kg/ha/year) x farm gate price (US$/kg)
Source: Calculated based on information collected from field survey (2010).

3.7.2 Fixed costs

The fixed costs accruing to prawn farming in rice fields relate to the depreciation of equipment (water pump, net and feed machine), land use costs or leases, and interest on operating capital. According to the survey, the average annual fixed costs for prawn

farming varied from US$375/ha in the extensive farming systems, to US$461/ha in the improved-extensive systems, and US$561/ha in the semi-intensive systems (Table 13). Fixed costs accounted for 26 percent, 22 percent, and 19 percent of total costs in extensive, improved-extensive and semi-intensive farms respectively.

3.7.3 Total costs

The average total annual cost of prawn farming per hectare varied from US$1 457 in the extensive farming systems, to US$2 088 in the improved-extensive systems, and US$2 875 in the semi-intensive systems (Table 13). Almost all the farmers that were interviewed indicated that the production costs had increased significantly over recent years as a result of increased input prices. As a result of high input costs, the production costs were highest for the semi-intensive farmers.

3.7.4 Gross revenue

Gross revenues are affected by the level of production and the market price attained. The market price of aquaculture products primarily depends on the size, weight, quality of the product, seasonality, and supply and demand issues (Ahmed *et al.*, 2009). The average farm-gate prices of prawns, fish and rice were calculated to be US$4.26, US$1.03 and US$0.22/kg, respectively. The average annual gross revenue per hectare varied from US$2 549 in the extensive farming systems, to US$3 533 in the improved-extensive systems, and US$5 037 in the semi-intensive systems (Table 13). Extensive farming is characterized by a relatively low level of production per hectare, and therefore gross revenues are low. In contrast, the semi-intensive farming systems attain a comparatively high level of production per hectare, and therefore gross revenues are correspondingly higher.

3.7.5 Net return

The highest average annual net return for prawn farming in rice fields was estimated at US$2 162/ha in the semi-intensive farming systems, followed by US$1 445/ha in the improved-extensive systems, and US$1 092/ha in the extensive systems (Table 13). Almost all the farmers in the survey indicated that their returns had decreased as the costs of prawn farming had increased, and furthermore that the price of prawns had not increased in line with increased production costs.

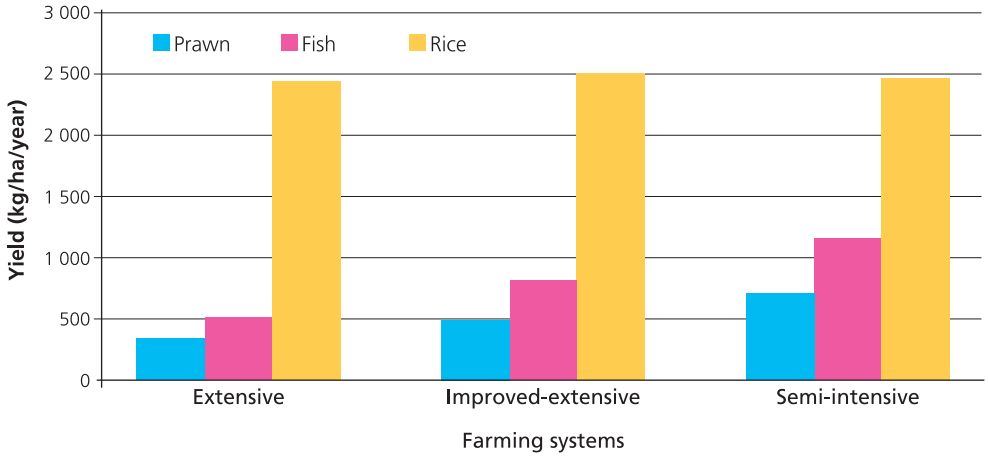
3.7.6 Benefit-cost ratios

The benefit-cost ratio (BCR), or profitability index, is defined as the gross revenue divided by the total costs. A ratio of 1 indicates that the operation is at a break-even point, i.e. costs and revenues are similar. A BCR greater than 1 indicates that the operation is producing positive net benefits. The BCR in the semi-intensive farming systems averaged 1.75. This indicates that the prawn farmers are able to recover US$1.75 for every US$1 of investment. The BCR in the extensive and the improved-extensive farming systems was calculated at 1.74 and 1.69, respectively (Table 13).

3.8 A comparison of the farming systems

Prawn, fish and rice production levels vary between the farming systems (Figure 14). Prawn productivity was the lowest in the extensive farming system. This was attributed to the use of snail meat as a prawn feed and to low farm inputs. In contrast, the highest level of productivity was observed in the semi-intensive farming system and attributed to the use of commercially manufactured pelleted feeds and the high level of farm inputs. Prawn production ranged from 351 kg/ha in the extensive farming systems, to 489 kg/ha in the improved-extensive systems, and 718 kg/ha in the semi-intensive systems (Table 11). Comparison with other prawn producing countries in Asia indicates that yields in Bangladesh are relatively low (Table 14).

FIGURE 14
Prawn, fish and rice productivity in different farming systems



Source: Field survey (2010).

TABLE 14
Comparison of prawn (*M. rosenbergii*) yields in Bangladesh and other Asian countries

Country	Yield (kg/ha/ year)	Reference
Bangladesh	351–718	Current study
China	1 500	Weimin and Xianping (2002)
India	600–1 000	Raizada *et al.* (2005)
Thailand	2 338	Vicki (2007)
Viet Nam	1 000–1 500	New (2005)

Prawn production is dependent on a number of factors including feed quality, farm size, stocking rates, fertilization and the management practices employed. The relative importance of production and feed conversion efficiencies depend upon the quality of the feed applied and management practices. Protein is the most important dietary component in fish diets and is of a primary concern in diet formulation (Bombeo-Tuburan *et al.*, 2001). The use of snail meat as prawn feed and cow dung as a fertilizer can in many respects be considered as organic farming. Snails are highly digestible and rich in protein, fat, vitamins and minerals. Freshwater snails contain between 37–68 percent protein, 6–11 percent fat and 3–6 percent glycogen, and provide a suitable feed for prawns. Moreover, on a dry weight basis, *P. globosa* contains between 4.74–5.59 kcal/g energy (Sing, 1991). The golden apple snail has a proximate composition of 54 percent crude protein, with an essential amino acid index of 0.84 (Bombeo-Tuburan, Fukumoto and Rodriguez, 1995).

Snail supplies are irregular and farmers often have to resort to using home-made feeds. Thus, using snail meat as a prawn feed cannot be considered a sustainable solution to the farmers' feed requirements. The snail population has become extinct in most areas where prawns are farmed. This is due to excessive harvesting during the monsoon which correlates with their reproductive season. Removal of the snails is also likely to result in an increase in the growth of some species of aquatic weeds which could reduce light penetration as well as photosynthesis, and could lead to eutrophication (Gain, 1998). The snail populations are important in maintaining a clean aquatic environment, and they serve an important function in terms of maintaining the balance between the aquatic weeds, other organisms, and the wetland soils. Over-harvesting the snails has

also created problems in terms of the disposal of large quantities of snail shells. In some cases this has resulted in pollution and the blockage of canals and waterways.

The cost of commercially manufactured pelleted feeds is a concern. The average unit price of commercial pelleted feeds (US$0.59/kg) is significantly higher than farm-made aquafeeds (US$0.35/kg), and snail meat (US$0.15/kg). Although the improved-extensive farmers are aware of the positive effects of using manufactured pelleted feeds, a lack of access to finance prevents them from buying and upgrading their production systems.

At present, the supply of commercially manufactured pelleted feeds is not an issue; however, if the sector expands rapidly, supplies may become limited. At annual production level of 23 377 tonnes of prawns in 2008 (FAO, 2010), and at an average FCR of 2.5:1, the annual feed requirement would be in the region of 58 443 tonnes. Currently prawn feed production is in the country is limited to 38 000 tonnes per annum (Chisty, 2009), and it must therefore be assumed that the feed requirements of the industry have to be partially met by the production of farm-made aquafeeds.

The use of farm-made aquafeeds is the best option for resource-poor farmers in terms of availability, quality and price (Table 15). Due to supply and environmental issues, snail meat feed is not a sustainable feed source. Thus, farm-made aquafeeds represent an appropriate feed production technology for use in Bangladesh. However, in order to increase production using farm-made aquafeeds, feed formulation and feed management practices need to be improved.

TABLE 15
A comparison of the aquafeeds that are currently available to the prawn farmers

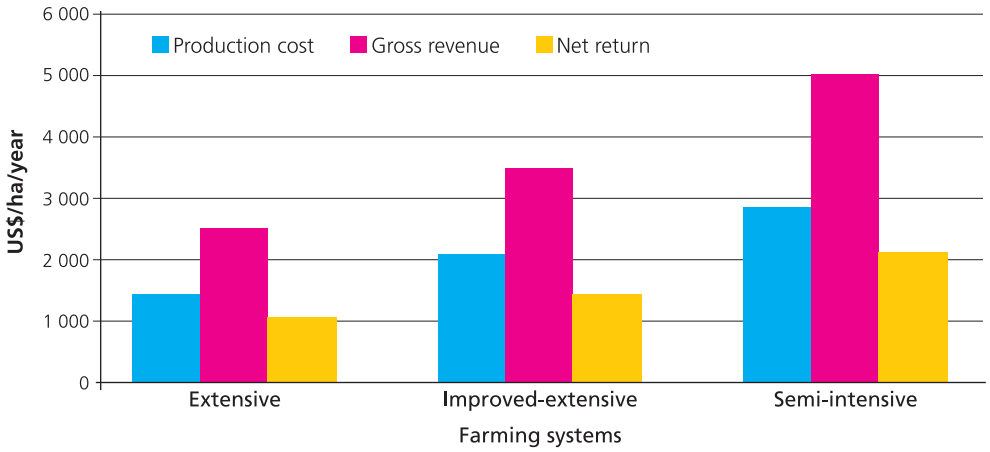
Feeding system	Positive attribute	Negative attribute
Snail meat	• Low-cost feed • Suitable for poor farmers • Natural source (organic farming) • Good proximate composition that satisfies the prawn nutritional requirements	• Low productivity • Restricted supplies • Cannot be used as a fish feed • Environmental costs associated with snail harvesting
Farm-made aquafeeds	• Use locally available and on-farm agricultural by-products • Comparatively low-cost • Moderate nutritional value • Suitable for both prawn and fish farming	• Lower feeding rate • Low level of prawn production • Poor production techniques are often employed
Commercially manufactured aquafeeds	• High nutritional value • Suitable for both prawn and fish farming • High productivity • High growth of prawns (large size of harvested prawns)	• High cost • Unsuitable for resource-poor farmers • Presence of banned antibiotics and human health concerns (i.e. carcinogenesis from banned antibiotics)

Source: Field survey (2010).

The results of the study show that the three farming systems have different cost structures and profitability (Figure 15). The production costs per hectare accruing to semi-intensive farms was significantly higher than those accruing to the other two production systems. Feed costs represents the highest single operational costs in semi-intensive farming systems, accounting for 33 percent of the total costs. Feed costs constitute the second highest operational cost in extensive (15 percent) and improved-extensive (25 percent) farming systems. The survey results indicate that the benefit-cost

ratio (Table 13) of using commercially manufactured pelleted feeds is only slightly higher than that attained by employing the two extensive systems. Reducing feed costs is an important consideration in terms of increasing profitability, and ensuring the long term sustainability of the industry. In terms of reducing feed costs, improving pond fertilization strategies can lead to a reduction in feed costs (Muir, 2003). Furthermore, the development of a feed based on low-cost locally produced ingredients could further help reduce feed costs and improve profit margins.

FIGURE 15
Production cost, gross revenues, and net returns in the three production systems



Source: Based on data from Table 13.

4. CONCLUSIONS

The sustainability of prawn farming among rural households with limited resources in southwest Bangladesh remains a challenge. Although using snail meat as a feed source is suitable for resource-poor farmers, relatively low levels of production are attained, and thus net returns are low. Moreover, feeding snail meat may not be environmentally sustainable in the long term. Higher net returns are obtained using semi-intensive culture techniques. Semi-intensive systems require more inputs than the extensive farming systems, and need the use of commercially produced pelleted feeds. However, the high costs associated with the use of pelleted feeds suggests that this type of farming would not be possible for a large number of small-scale and resource-poor farmers. The quality of these feeds is also of concern as some reportedly contain banned antibiotics. It is recommended that the feed manufacturers use quality raw materials to produce their feeds, and that imported feed ingredients such as meat and bone meal should be free from banned antibiotics.

Feed cost is one of the major constraints to the expansion of the sector. The development of a low-cost feed to replace or reduce the dependence on snail meat is required. Feed formulations based on low-cost, locally produced ingredients would help to improve profit margins, and reduce the negative environmental impacts associated with snail harvesting. According to Shang, Leung and Ling (1998), the unit cost of farm-made feeds can be lowered using locally available feed materials, thus negating the need to use commercially manufactured aquafeeds. This being the case, it is evident that farm-made aquafeeds provide the best prospects for developing cost effective feeds. Such feeds would be suitable for use by resource-poor farmers in terms of availability, quality and price. Farm productivity can also be improved by increasing feeding rates and improving feed management practices. Most prawn farms could

become more efficient by adjusting inputs, and there is sufficient scope to increase production as well as profits by increasing inputs, including farm-made aquafeeds.

Although farm-made aquafeeds provide the best prospects for supplying cost effective feeds to the industry, technical support in terms of raw material selection, storage, processing, feed formulation and preparation needs to be improved. There is also a need for research programmes to focus on developing cost effective feed formulations, and improving feeding strategies. The knowledge base of extension workers needs to be enhanced so that farmers can be taught to improve their farming practices. Institutional support could also be used to improve farm-made aquafeed production and marketing.

While extensive and improved-extensive farmers are aware of the positive effects of increasing inputs, a lack of capital has prevented them from engaging in semi-intensive farming. Access to capital could be improved by providing low interest credit through government sources, NGOs and commercial banks. In addition, training would help to improve productivity, profitability and reduce risks. Improving management capacity requires the provision of adequate training (Jahan, Beveridge and Brooks, 2008), and in this regard, farmer training represents a relatively low cost method that could be used to improve production efficiencies.

4.1 Recommendations

The following recommendations are suggested to improve feed management practices:

- The use of farm-made aquafeeds can increase farm productivity and profitability. Farmers and associated groups often lack the basic technical knowledge to optimize feed management practices. Feed management training programmes should be provided. The Department of Fisheries and NGOs should be approached to assist in the provision of these services. Moreover, successful prawn farmers with this knowledge could be used as trainers for farmer-to-farmer training programmes.
- The use of farm-made aquafeeds can increase farm productivity and profitability. Farmers should be encouraged to use these feeds. Farm-made aquafeeds that use low-cost, locally produced ingredients should be developed.
- Technical support with respect to raw material selection, storage, processing, feed formulation and the preparation of farm-made aquafeeds should be improved. Technical support, training and extension services should be sought from the Department of Fisheries.
- Government support and the development of public-private partnerships could be used to improve the production capacity, the quality of feeds, and marketing systems.
- The quality of commercially produced pelleted feeds needs to be improved. It is recommended that the commercial feed industry should only use high quality raw materials in their feeds. Government control over the trade of commercially manufactured pelleted feeds should be improved in terms of quality control and the development of marketing systems.
- Access to finance remains a problem for resource-poor farmers. Assisting farmers to obtain cheaper credit would enable them to increase feed use and become more profitable. Access to finance at zero or very low interest rates could be provided by the government/national banks.

4.2 Further research

Applied research in areas such as quality feed production using low-cost locally available feed ingredients and on-farm by-products needs to be given particular attention. Research interventions should take into consideration existing technologies and the transfer, adaptation and development of new technologies. Issues of environmental sustainability in terms of feed use are poorly understood, and further research is

required to determine the quantitative and qualitative environmental impacts that accrue to feed use. Considering the lack of information services among feed producers, distributors, marketing agencies, and development and research institutions, the establishment of an information network related to aquafeeds needs to be given special attention.

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On-farm feed management practices for black tiger shrimp *(Penaeus monodon)* in India

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ABSTRACT

This paper is based on a case study of on-farm feed management practices for the black tiger shrimp (*Penaeus monodon*) culture in India. Ninety percent of shrimp farming in India is a small-scale farming activity. Feed is the largest cost input in shrimp farming, accounting for 50 to 60 percent of production costs. Reducing feed costs through improvements to feed management practices is essential to improving the economic performance of the culture operations. The study was carried out in 2010, and focused on four different types of farming systems that were based on different stocking densities, and used either manufactured or farm-made feeds.

The review assesses feed use in small-scale shrimp aquaculture, with particular emphasis on the use and selection of feed types. The paper also provides an overall assessment of feed management practices and feed utilization. The review identifies feed practices and feed specifications, and provides practical measures that can be taken to improve on-farm feed management. The study revealed that 98 percent of the shrimp farmers in India used manufactured sinking dry pellets, and only two percent (the extensive farmers) use farm-made feeds. Currently, feeds produced by the big aquafeed manufacturers dominate the market, and, through local feed dealership networks, these feeds are available in all the farming areas. In the study, 36 percent of the farmers reported Food Conversion Ratios (FCR) of 1.2:1 to 1.4:1; 37 percent recorded FCR greater than 1.4:1; and the remaining 27 percent recorded FCR below 1.2:1. The farmers in the survey indicated that an FCR of <1.5:1 was adequate.

Issues related to feed management are discussed, and recommendations to promote capacity building and improved management through the clustering of small-scale shrimp farmers are made. These recommendations are designed to reduce risk, promote good on-farm feed management practices and reduce feed and feed ingredients costs. Research recommendations that are driven by commercial realities are provided, the policy and regulatory frameworks are analyzed and appropriate interventions to support sectoral growth provided.

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1. INTRODUCTION

1.1 Global trends in black tiger shrimp production

Shrimp farming is one of the most profitable and fastest-growing sectors of the aquaculture industry. Over the past decade, global farmed shrimp production has grown almost threefold from 1.13 million tonnes in 1999 to over 3.43 million tonnes in 2009 (Jory, 2010). A number of factors have contributed to this phenomenon. In the 1980s the growing demand for shrimp, mainly from North America, Europe and Japan, coupled with a levelling-off of production from capture fisheries, resulted in high market prices (Neil *et al.,* 2001). Within the last 20 years, major technical improvements have been made to farming systems. These include the emergence of new production technologies and the production of pellet feeds with high protein levels. These advancements have enabled farmers to stock at higher densities, increase yields and correspondingly increase profitability. These successes have provided the impetus for increased investment in shrimp aquaculture (Naylor *et al.,* 2000).

Global production of black tiger shrimp increased from about 21 000 tonnes in 1981 to almost 200 000 tonnes in 1988; by 1993, production had increased to nearly 495 000 tonnes with a value of US$3.2 billion (FAO, 2012). Since 1993, production has been variable, ranging from a low of ~480 000 tonnes in 1997 to a high of 781 582 tonnes in 2010.

Since 2003, *P. monodon* production has declined in Thailand. This decline is due to various factors including disease and the poor quality of *P. monodon* seed (Wyban, 2007). Diseases affecting *P. monodon* include white spot syndrome virus (WSSV), yellow head virus (YHV), monodon baculovirus (MBV) and to a lesser extent, luminescent bacterial infections. In addition, poor quality *P. monodon* seed has restricted the expansion of the industry. Poor quality seed, coupled with the slow growth of *P. monodon*, is encouraging farmers to switch to the production of whiteleg shrimp, *Litopenaeus vannamei* in several countries. Domestication technologies and the development of disease-free broodstock is a major requirement for sustaining *P. monodon* farming and increasing production parameters (Flavio Corsin, International Centre for Aquaculture and Fisheries Sustainability, personal communication, 2010; Wiwath, Department of Fisheries, Hanoi, Viet Nam, personal communication, 2010; Arun Padiyar, FAO Consultant, personal communication, 2010).

Asia, particularly South East Asia, is the most important shrimp producing region of the world. Asia has favourable natural resources for shrimp production, with the coasts of the Pacific and Indian oceans providing suitable culture areas. The climate in Southeast Asian countries is tropical or subtropical, and provides favourable conditions that are suitable for shrimp production (Xinhua, 2008). In 2010, all farmed *P. monodon* was produced in Asia (FAO, 2012); the major producers were Viet Nam (333 000 tonnes), Indonesia (125 519 tonnes), India (96 500 tonnes), China (56 634 tonnes), the Philippines (48 162 tonnes), Myanmar (46 105 tonnes) and Bangladesh (43 154 tonnes). The majority of farmed shrimp from India is exported to the European Union, the United States and Japan (MPEDA, 2008).

India, the third largest producer of *P. monodon*, possesses an extensive coastline, measuring approximately 8 000 km. The country utilizes only about 40 percent of the available 2.36 million hectares of freshwater resources that are suitable for pond and tank aquaculture, and 13 percent of the 1.2 million hectares of brackishwater resources. Between 1990 and 1994 there was a phenomenal increase in the area under shrimp culture. The increase in production was primarily a result of strong international demand for shrimp, combined with the development of commercial hatcheries, credit facilities from commercial banks, and technical and financial assistance programmes from the Marine Products Export Development Authority (MPEDA), the Indian Council of Agricultural Research (ICAR) Institutes and the State Fisheries Departments (De Silva and Davy, 2010). Indian shrimp farming is mainly based on black tiger shrimp, which contributed 86 percent

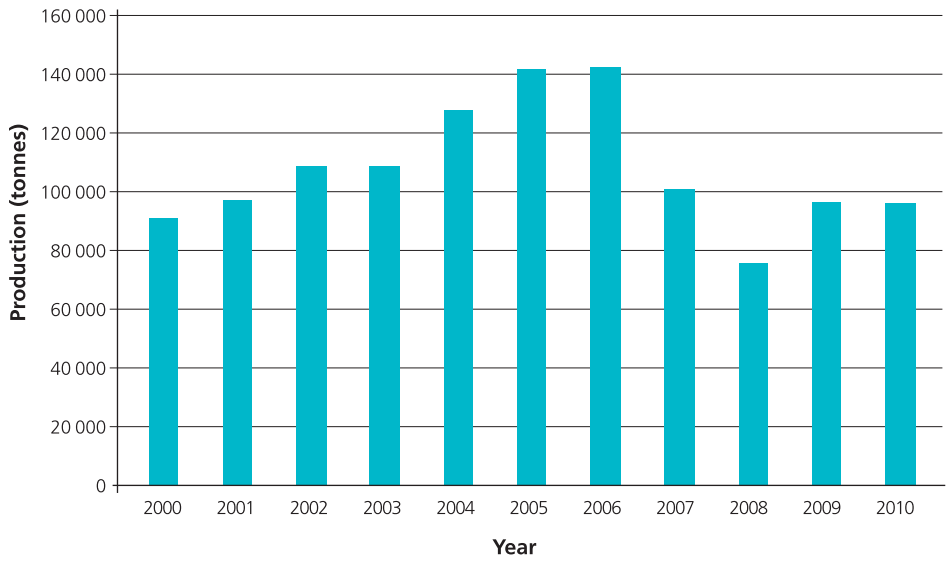
to the national shrimp and prawn production (112 100 tonnes) in 2010 (FAO, 2012). In the mid-1990s in Andhra Pradesh and Tamil Nadu, a large number of integrated commercial shrimp farms were developed. These facilities adopted modern culture practices and included production facilities for shrimp seed, feed and processing. Unfortunately, the advent of viral diseases in the region made these large-scale integrated facilities unprofitable, and shrimp culture there has now largely reverted to a small-scale farmer activity.

Currently, coastal aquaculture in India is synonymous with shrimp aquaculture and is mainly carried out by small-scale farmers (MPEDA, 2009). It comprises three categories of farmers/entrepreneurs, *viz.* small- to medium-scale farmers, middle-level entrepreneurs and large-scale entrepreneurs. At present, 91 percent of the shrimp farmers in India own less than two hectares, six percent own between two to five hectares and the remaining three percent own more than five hectares (MPEDA, 2009). Out of the total area devoted to aquaculture, 0.152 million hectares is currently being utilised for shrimp farming. The state of Andhra Pradesh alone provides 47 percent of the area and contributes 50 percent of the total production (FAO, 2005a). Small-scale farmers contribute around 80 percent to the total *P. monodon* production (MPEDA, 2009). There are 283 *P. monodon* hatcheries operating in the country, which provide a total production capacity of 12.0 billion postlarvae/year. Prior to the establishment of shrimp feed factories, shrimp feed was imported from Thailand, Taiwan Province of China and other countries but, by 2009, national shrimp feed production was 150 000 tonnes (MPEDA, 2009).

In India there are two distinct seasonal shrimp crops. The first crop starts in February or March and ends in May or June. The second crop starts in August or September and ends in November or December. Typically the first crop produces a much higher yield than the second crop (Suresh, 2007). Warm weather in summer is cited to be the main reason for this difference. The average duration of each production cycle is 120 to 140 days, and the average size of *P. monodon* harvested ranges from 20 to 40 g.

Shrimp farms use land that is either leased from the government or the private sector, or land that is owned and operated by the shrimp farmers. A credit system is available to the farmers, primarily operated and controlled by intermediaries who also act as input suppliers at each stage in the supply chain, and also purchase the harvested shrimp. On average, farmers pay 25 to 30 percent interest on the loans from these intermediaries, significantly affecting the profitability of their operations (De Silva and Davy, 2010).

FIGURE 1
Production trends of *Penaeus monodon* in India (2002–2010)



Source: FAO (2012).

Farmed shrimp production increased from 40 000 tonnes in 1991–1992 to 143 170 tonnes during 2006–2007, generating export sales valued at US$0.8 billion (MPEDA, 2008). In recent times, black tiger shrimp production in India declined from a peak of 142 967tonnes in 2006 to 96 500 tonnes in 2010 (FAO, 2012) (Figure 1).

The recent decline in production was probably due to the low market price for this species in 2007. In recent years, many farmers have felt that the returns from *P. monodon* farming have declined, and as a result the area under farming became reduced from a peak of 149 600 hectares during 2006 to 76 000 hectares (MPEDA, 2009). With the improved market price for *P. monodon* during 2008, the farming area in 2009 was increased to 102 200 hectares. During 2010, the farming area grew to 113 852 ha and production rose to 118 575 tonnes (MPEDA, 2010).

1.2 Market trends

Globally, shrimp is the most valuable traded aquaculture commodity, and in 2006, it accounted for 17 percent of the total value of internationally-traded fishery products (FAO, 2008); however, despite growing global export volumes, its share has been declining, with average prices showing a downward trend. In value terms, the major exporting countries are Thailand, China and Viet Nam (Jory, 2010). The EU is the main market for shrimp exports from India and, with the exception of the United Kingdom, all the major European countries are currently experiencing a stable or increasing trend in consumption. In the first half of 2010, the prices remained high for black tiger shrimp; compared to 2008, prices increased by almost US$2/kg (30 to 40 g shrimp). In addition, there was a general increase in domestic shrimp consumption in countries such as China and Thailand and, more recently in India. An increase in demand for organically certified shrimp from developed countries is anticipated over the coming years. This is attributed to growing health consciousness among consumers in these countries.

1.3 Legislation, policy and regulatory frameworks

No national standards have been set for the nutrient composition of shrimp feeds. However, recently the Coastal Aquaculture Authority of India started a feed manufacturer registration programme, and feed standards are being developed in collaboration with research institutes. The mandatory legislative requirements for *P. monodon* production in India (FAO, 2005b) comprise:

- Legislative acts: the government of India enacted the Coastal Aquaculture Authority Act (2005), establishing the Coastal Aquaculture Authority (CAA) that is mandated to enforce aquaculture regulatory measures in the coastal zone and promote environmental sustainability in the sector. The Act excludes freshwater aquaculture, but encompasses all forms of aquaculture in saline or brackishwaters in the coastal zone.
- Legislative Requirements for feed and feed manufacturers: all shrimp feed manufacturers are required to be registered by the CAA. The CAA has the power to review the registration of feed mills and, where necessary, to take appropriate management actions.
- Regulatory frameworks: There is no legally binding regulatory framework in place. However, voluntary guidelines are being developed.

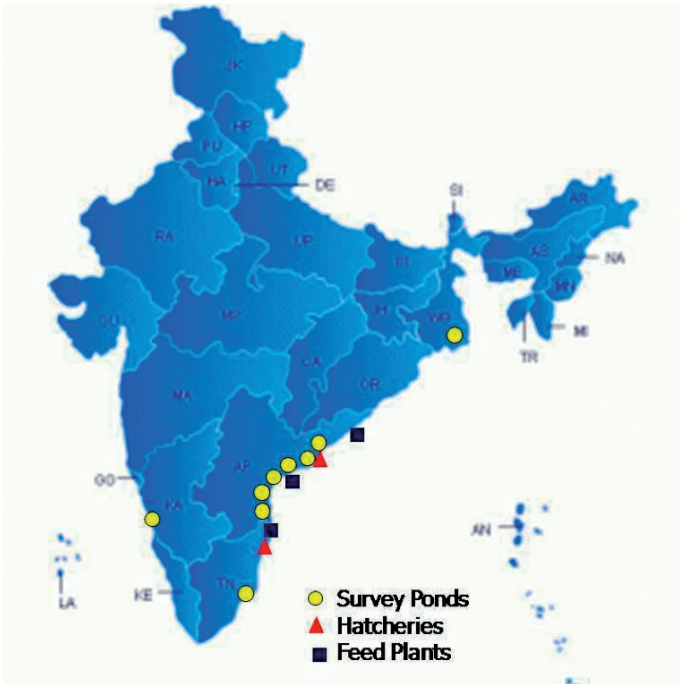
2. METHODOLOGY

The study focused on four types of farming systems that use different stocking densities and feed types. A number of data sources were interrogated; data on feeding practices and the average Feed Conversion Ratios (FCR) were obtained. The survey was undertaken during the summer crop of 2010, and included 183 ponds located across three states on the east coast of India, namely Andhra Pradesh, Tamil Nadu and West Bengal, and one state on the west coast, Karnataka (Figure 2 and Table 1).

Twenty-eight ponds from traditional farms which use supplementary feeds in West Bengal were included in the survey. The survey was carried out by field staff of the National Centre for Sustainable Aquaculture. During the survey it was apparent that shrimp farmers predominantly use commercially manufactured pelleted feeds, and a small percentage of traditional farms make their own farm-made feeds using locally available ingredients. The feeding practices applied and the type of commercial feeds used at different stages of the growth cycle were established. All the farmers practiced *P. monodon* monoculture and all were members of aquaculture societies. Aquaculture societies constitute a group of aquaculture farmers in a specific locality who use participatory approaches for reducing disease risks, production costs, and meet market demands through sustainable farming (De Silva and Davy, 2010). Each society comprises 20–50 farmers who have registered their farms with the Coastal Aquaculture Authority (CAA). Membership is voluntary and subject to certain conditions. Broodstock feed and feed management data was collected from the hatcheries that supplied seed to the study farms, and information pertaining to the raw material sources used in the manufactured feeds was collected and collated.

The four states (Table 1) that were selected for the study (Figure 2) produce 81 percent of total farmed shrimp in India (MPEDA, 2008).

FIGURE 2
Map showing the study area



Source: Field survey (2010).

TABLE 1
Distribution (% of ponds surveyed) of the farming systems included in the survey

Farming system	Stocking density	Andhra Pradesh	Karnataka	Tamil Nadu	West Bengal
Traditional	<2 postlarvae/m²				13.27
Extensive	<4 postlarvae/m²	24.28	0.00	0.00	
Modified extensive	4–8 postlarvae/m²	26.63	6.60	5.20	
Semi-intensive	>8 postlarvae/m²	22.55	0.69	0.78	
			n = 183		

Source: Field survey (2010).

2.1 Farming systems

The farming systems currently employed in India can be broadly divided into four basic categories: traditional farming systems (TFS), extensive farming systems (EFS), modified extensive farming systems (MEFS) and semi-intensive farming systems (SIFS). At present, there is no intensive *P. monodon* farming in India.

2.1.1 Traditional farming systems (TFS)

TFS are polyculture systems that are based on earthen ponds ranging in size from <1 hectare to 25 hectares. The systems are characterized by low stocking densities of less than 2/m², hatchery or wild postlarvae/juveniles, and in the smaller ponds, the limited use of supplementary feeds. This type of traditional coastal farming – locally known as *Bheri*-culture in West Bengal – is primarily practiced in the states of West Bengal and Kerala. The farms rely on tidal water exchange to replenish natural food sources. The stocking is undertaken on a monthly basis, and the larger shrimp are harvested every fortnight during full moon. Due to the open tidal water exchange nature of the system, other fish and shrimp species are also found in the ponds. Typically, shrimp production is less than 300 kg/ha/year and in 2008 the estimated national production attributable to this farming system was 26 000 tonnes (27 percent of total *P. monodon* production) (MPEDA, 2009).

As a polyculture system, other species that are cultured include *Metapeneaus monoceros* (speckled shrimp) *Lates calcarifer* (Asian seabass), *Liza tade* (rock mullet), *Mugil cephalus* (striped mullet) and *Anguilla* sp. (eel). When the salinity falls below 10 ppt during the monsoon season, additional species are also produced, including *Macrobrachium rosenbergii* (giant river prawns, known in India as 'scampi'); the carps *Labeo rohita* (rohu), *Catla catla* (catla) and *Cirhinnus cirrhosus* (mrigal); and *Oreochromis niloticus* (Nile tilapia).

2.1.2 Extensive farming systems (EFS)

The EFS system is based on earthen ponds ranging in size from 0.5 to 2 hectares, which are characterized by low stocking densities of less than 4/m², using hatchery-reared postlarvae (PL)/juveniles, and the use of manufactured feeds. Shrimp production is <500 kg/ha/year. In 2008, the estimated national production attributed to the farming system was 21 000 tonnes (22 percent) (MPEDA, 2009).

2.1.3 Modified extensive farming systems (MEFS)

The MEFS system is based on earthen ponds ranging in size from 0.5 to 1.5 hectares. The system employs low water exchange rates (tidal or pumped systems, with up to ten percent of water exchange per day), use intermediate stocking densities (4 to 8 PL/m²), hatchery-produced PL, and manufactured feeds and some fertilization. Low labour inputs are required, and these systems are usually operated by family members. Partial aeration is used at night and in the early morning when dissolved oxygen levels in the pond waters are at their lowest. These farms tend to produce moderate shrimp yields of 1–2 tonnes/ha/year. In 2008, the estimated national production using this farming method was 29 000 tonnes (30 percent) (MPEDA, 2009).

2.1.4 Semi intensive farming systems (SIFS)

Typically SIFS farms use small to moderate-sized earthen ponds (0.3–1.0 ha), with moderate water exchange (pumping: 5–20 percent water exchange/week). Shrimp stocking densities range from 8–20 shrimp/m², and stocking is based on hatchery-produced PL. Manufactured pelleted feeds are used and the ponds are continuously aerated. Aeration rates increase during the final production phase. Fertilization and moderate labour inputs (one worker per 2 ha of ponds) are required. Semi-intensive farms produce shrimp yields of 2.0-4.0 tonnes/ha/crop. In 2008, the national production in SIFS was approximately 20 000 tonnes (21 percent) (MPEDA, 2009).

2.2 Hatchery production

Shrimp hatcheries comprise separate facilities for spawning, hatching, larval and PL rearing, indoor and outdoor algal culture (where applicable), and areas for hatching *Artemia* and feed preparation. Thirty percent of the larger hatcheries use separate biosecure production units for each production stage. Typically, the hatcheries comprise two to four production units with each unit comprising 10–20 separate tanks. Hatcheries attempt to stock all their tanks in each unit simultaneously in order to reduce biosecurity risks.

In addition, there is supporting infrastructure for the handling of water (facilities for abstraction, filtration, storage, disinfection, aeration, conditioning and distribution); there are diagnostic laboratories, areas for the maintenance and packing of nauplii and PL; and there are offices, storerooms and staff living quarters and facilities.

The *P. monodon* hatcheries in India primarily rely on wild shrimp broodstock; only two hatcheries are producing shrimp seed in maturation systems. Those hatcheries that mature their broodstock feed the animals with fresh squid (*Loligo* sp.) at 6–10 percent wet body weight/day, clams (4–8 percent wet body weight/day), polychaete bloodworms (10–12 percent wet body weight/day), and tuna fish eggs and goat liver at a combined total of 20–30 percent of wet body weight/day. All the maturation feed is procured from local sources. The exact quantity of feed provided is adjusted frequently, and is based on consumption rates within individual tanks. The feeding is to satiation and is continued until only a very small amount of uneaten food remains in the tank a couple of hours after each feeding.

3. RESULTS

3.1 Farming practices

For several decades, traditional farming has been practiced in the states of West Bengal (*Bheri* farmers) and Kerala. In February, ponds are filled during high tide, and PL that are either wild-caught or sourced from hatcheries are stocked at 15 000/ha. After two months of culture partial bi-weekly harvesting starts; 7 500 PL/ha are stocked immediately after each partial harvest and the final harvest takes place after approximately 10 months. *Bheri* farmers procure seed from commercial nurseries that are supplied with PL from the hatcheries. The dependence on commercial nurseries for seed in West Bengal is due to the small quantities that the farmers require to stock their ponds. Farmers feel it is not feasible for them to procure PL directly from the hatcheries because they would be required to purchase large numbers of animals. The production cycle in this system is approximately 10 months.

3.1.1 Pond preparation and Fertilization

The ponds in the traditional extensive production systems are not treated prior to stocking – they are large and they cannot be completely drained. In the other production systems, the ponds are drained and sun-dried for one to two months, and treated with lime in order to obtain the ideal soil pH. Ponds are filled to an average of one metre and fertilized with either inorganic or organic fertilizers. The inorganic fertilizers include urea, diammonium phosphate (DAP), superphosphate and potash. These are mixed in the water and spread throughout the pond. Organic fertilizers, such as fermented mixtures of molasses (locally known as *jaggary* – a by-product of the sugar industry), rice bran and yeast may be used. These are spread across the ponds at a ratio of 25:10:0.25 kg/ha.

Different fertilization regimes result in differential yields (Table 2). Seventy-eight percent of farms that were surveyed apply fertilizers to generate plankton blooms prior to shrimp seed stocking. These phytoplankton populations are maintained during the culture period. No inorganic fertilizers are applied after the first month of culture.

Fermented mixtures of molasses, rice bran and yeast are commonly used throughout the production cycle to maintain plankton blooms, and to keep the pH at acceptable levels (pH 7.5–8.5). Oil cakes are also used. The prices ranged from US$0.11–1.07/kg for inorganic fertilizers and from US$0.28-0.64/kg for organic fertilizers, except yeast, which was US$12.79/kg (Table 3).

TABLE 2
Use of fertilizers at different stocking densities and the resultant production of shrimp

Stocking density (PL/m^2)	No fertilization	Inorganic fertilization	Organic fertilization
	Production (kg/ha)		
1	154		
2	483	404	567
3		538	756
4		854	974
5	1 233	1 554	1 646
6	1 550	1 695	1 791
7			
8		2 500	1 883
9	1 733		3 087
10			2 781
11			3 186
12			3 280
13			2 908
14			3 409
15			1 516
17			4 178

Note: Inorganic fertilizers used are urea, DAP and superphosphate; organic fertilizers comprise a combination of molasses, rice bran, yeast and oil cakes.
Source: Field survey (2010).

TABLE 3
Prices and usage of fertilizers in study ponds

	US$/kg	Application rate (kg/ha)
Urea	0.14	12.5–25
DAP	0.22	50–125
Superphosphate	0.11	125
Ground nut oil cake	0.51	35
Rice bran	0.28	70
Molasses	0.64	2.5
Yeast	12.79	0.6
Potash	1.07	13

Source: Field survey (2010).

3.1.2 Shrimp seed procurement and stocking

The survey revealed that 93 percent of the farmers procured *P. monodon* seed through a contract system whereby farmers purchase quality seed in bulk. The farmers enter into an agreement with a hatchery operator one month in advance of delivery. Seventy percent of the seed used in the traditional extensive farming systems were procured from commercial hatcheries, and rest were sourced from the wild. In the modified extensive farming systems and the semi-intensive farming systems, the seed was sourced exclusively from commercial hatcheries. Hatcheries in the state of Andhra Pradesh supplied 90 percent of the seed to the study farms. Farmers procure seed from local hatcheries that are in close proximity to their farms (<8 hrs transportation time). When the transportation time exceeds four hours, the PL are stocked directly into the ponds during the early morning hours. When the transportation periods are less than four hours, the PL are stocked during the late evening. After 45 days, survival estimates are made. These are based on feed consumption rates (using feed trays), and cast net sampling. Until the survival estimations have been made, 80 percent of PL are assumed to have survived, and feed rates are adjusted accordingly.

3.2 Feed

3.2.1 Farm-made feeds

While twenty percent of the extensive farms reported using farm-made feeds (Figure 3, left), the study also revealed that 98 percent of the shrimp farmers used manufactured, sinking dry pellets (Figure 3, right) in combination with farm-made feed. Only 20 percent of the extensive farms (<2 percent of the total farming area in the country) were using farm-made feeds; the other 80 percent of the extensive farmers, and all of the modified extensive farms and semi-intensive farms used manufactured, sinking pelleted feeds.

The traditional extensive farms in West Bengal (*Bheris*) that are larger than two hectares do not use feeds, and the shrimp therefore rely on the natural productivity in the ponds for nutrients. The natural food is replenished by regular water exchange during high tide periods. On the smaller modified extensive farms, farm-made feeds are used and are primarily comprised of mixtures of boiled rice, maize and potatoes. During the first month of the production cycle there is no feeding, and the shrimp depend solely on natural pond productivity. In the second month feed is provided once per day, up to a maximum of 7.5 kg/ha. Groundnut, rice bran, wheat cake and egg yolk are used as ingredients (Figure 4). The average price of farm-made feeds is US$0.32–0.42/kg. From the third month, feeding is based on the size of the shrimp, and a minimum of 7.5 kg/ha is fed per day.

FIGURE 3
Aquafeed used for shrimp aquaculture in India

COURTESY OF FAO/UMESH N. RAMASWAMY

Note: Left: farm-made feed; right: commercially manufactured sinking pellets

FIGURE 4
Crumbled feed mixed with water to aid distribution in the pond

COURTESY OF FAO/UMESH N. RAMASWAMY.

3.2.2 Industrially manufactured pelleted feeds

India has a well-established capacity to produce shrimp aquafeeds. Prior to 1990, when the manufacturing aquafeed industry was in its infancy, the country relied on farm-made feeds. In the early 1990s, large quantities of shrimp feeds were imported from Taiwan Province of China and Thailand. Over time, these imports have gradually been replaced by domestically produced feeds. Currently, domestic shrimp feed production capacity exceeds demand. Approximately 3 000 tonnes of shrimp feed is imported from Indonesia, China, Taiwan Province of China and South Africa to cater to the needs of niche markets (Suresh, 2007).

3.2.3 Quality Requirements for Shrimp Feeds

As farms in India evolve from low to high stocking densities, the quality of feed becomes increasingly important. Extensive farms use feed and also fertilize their pond waters to stimulate natural productivity. In semi-intensive farms, the shrimp primarily depend on pelleted feeds, and therefore the quality of the feed is more important because the shrimp derive their nutrition from exogenous feed inputs.

The respondents in the survey reported that the key factors that determine shrimp feed quality are its palatability, water stability and ingredient composition. The farmers assess the palatability of the feed quantitatively, based on feed intake, growth and FCR – an unpalatable feed would not be eaten, manifesting in a reduction in growth rates and poor FCR. Water stability is established by the farmers by placing a few feed pellets in a glass of water and establishing the condition of the pellets after 3 hours. If the pellets remain intact and do not disintegrate when the water is mildly stirred, it is considered as having good water stability. Farmers consider fishmeal to be one of the important ingredients in determining feed quality, and on receipt of a new batch of feed, the farmers smell the product to ascertain that it contains sufficient fishmeal. While this is not an accurate way to test the ingredient composition of the feed, it gives the farmers an idea of the quantity of fishmeal being used in the feed. Farmers reported that feeds with a good fishmeal odours provide good results in terms of growth and FCR.

The Marine Products Export Development Authority (MPEDA) has prescribed quality norms based on ingredient composition for shrimp feeds that can be sold in India (Table 4).

TABLE 4
Quality norms prescribed by the MPEDA for shrimp feeds sold in India (quantities stated as proportions of dry feed)

Proximate composition	**Starter**	**Grower**	**Finisher**
Crude protein (%)	40–45	30–35	30–35
Non-protein nitrogen (%)	<0.2	<0.2	<0.2
Crude lipid (%)	6–8	6–8	6–8
Crude fibre (%)	3–4	3–5	3–5
Digestible energy (10^3 calories/kg of feed)	3 200–3 600	3 200–3 600	3 200–3 600
Fatty acids			
Linoleic acid + linolenic acid (%)	0.5	0.5	0.5
Eicosapentenoic acid (EPA) + decosahexaenoic acid (DHA) (%)	0.5	0.5	0.5
Phospholipids (lecithin) (%)	1	0.4	0.4
Cholesterol (%)	0.5	0.2	0.2
Astaxanthin (ppm)	-	-	200
Essential amino acids			
Arginine (%)	2.03–2.32	1.74–2.03	1.74–2.03
Isoleucine (%)	1.225–1.4	1.05–1.225	1.05–1.225
Methionine (%)	0.84–0.96	0.72–0.84	0.72–0.84
Phenylalanine + tyrosine (%)	1.89–2.16	1.62–1.89	1.62–1.89
Phenylalanine (%)	1.4–1.6	1.2–1.4	1.2–1.4
Tryptophan (%)	0.28–0.32	0.24–0.28	0.24–0.28
Histidine (%)	0.735–0.84	0.63–0.735	0.63–0.735
Lysine (%)	1.855–2.12	1.59–1.855	1.59–1.855
Threonine (%)	1.26–1.44	1.08–1.26	1.08–1.26
Valine (%)	1.4–1.6	1.2–1.4	1.2–1.4

Source: MPEDA (2009).

3.2.4 Feed production

The aquafeed manufacturing industry has evolved significantly from the early 1990s, when small-scale shrimp feed manufacturers dominated the market. Prior to the white spot syndrome virus (WSSV) disease outbreaks in the mid-1990s, the market was dominated by small unorganized feed manufacturers. The sector comprised 30–40 feed mills that, in addition to producing shrimp feeds, also manufactured cattle and poultry feeds. During 1995–96, multinational companies, including CP, President, Gold Coin, and a few manufacturers from Taiwan Province of China, started importing feeds. From the mid-1990s, these feed manufacturers started developing large manufacturing plants that were dedicated to shrimp aquafeed production. Today, the feed produced from these plants dominates the market. India has 28 shrimp feed mills, both large and small, with an installed capacity of approximately 1 900 tonnes per day (Table 5) with a total installed production capacity exceeding 500 000 tonnes per year[2]. Out of these, six or seven manufacturers are manufacturing feeds in collaboration with overseas companies that provide technical assistance.

[2]Assumes >263 working days per year; normally there would be over 300.

TABLE 5
Distribution and installed capacity of shrimp feed manufacturing plants in India

State	Number of feed plants	Installed capacity (tonnes/day)
Andhra Pradesh	21	1 060
Tamil Nadu	6	720
Kerala	1	120
Total	28	1 900

Source: Suresh (2007).

3.2.5 Feed ingredients

The manufactured aquafeeds reported during the survey contain approximately 40 essential nutrients. About 20 to 40 percent of the ingredients used in commercial shrimp feeds are derived from marine capture fisheries, which include fishmeal, fish oil, shrimp/crustacean meal, squid meal and other miscellaneous products, such as fish, fish silage, fish/squid-liver meals and seaweed extracts (Table 6).

The principal classes of raw materials that are currently used in the shrimp aquafeeds can be classified as:

- Cereals and cereals by-products.
- Leguminous seeds.
- Vegetable oil residues.
- Animal by-products and oils.
- Miscellaneous ingredients, including vitamins and minerals.

TABLE 6
The key aquafeed ingredients used in the manufacture of shrimp feeds and their cost

Feed ingredient	Typical price	
	(INR/kg)	(US$/kg)
Fishmeal	51	1.10
Shrimp head meal/shrimp shell meal	27	0.58
Squid liver powder	280	6.05
Cod liver oil	33	0.71
Wheat flour	17	0.37
Wheat bran	13	0.28
De-oiled rice bran	8	0.17
Soybean meal	21	0.45
De-oiled groundnut cake	22	0.47
Cereals	12	0.26
Maize	12	0.26
Broken rice	11	0.24
Rape seed	15	0.32
Feed additives		
Soya lecithin	59	1.28
Cholesterol (95% pure)	2 311	50
Di-calcium phosphate	25	0.54
Vitamins and minerals	40	0.86
Lysine	127	2.75
Choline chloride	60	1.3
Antioxidant (ethoxyquin)	200	4.3
Binder – gluten	99	2.14

Notes: US$1.00 = INR 46.4 (2010 exchange rate).

Source: Field survey (2010).

In the past, feed manufacturers primarily depended on fishmeal imported from either Chile or Peru. Over the past few years, fishmeal produced in India is starting to be used by many feed manufacturers. With the assistance of the feed manufacturers, the quality of the locally produced fishmeal has been improved. Local fishmeal plants have invested in machinery, and are now producing good quality fishmeal with protein levels of up to 62 percent. Plant based ingredients, including soya flour, full fat soya and soya lecithin from India are also used. Various imported vitamins and minerals are added to the formulations.

3.2.6 Feed selection and availability

The respondents reported a number of factors that affected their choice of feed. The key factors included:

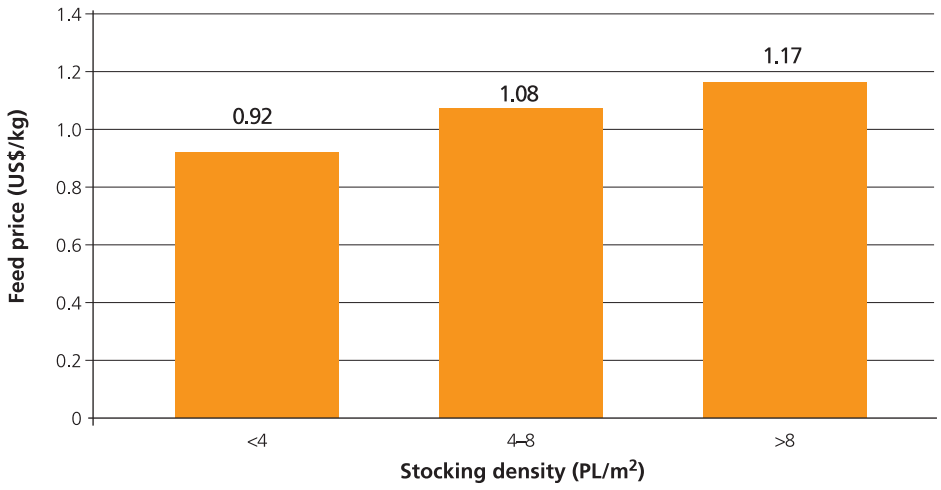
- Feed quality
- Previous experience of using the feed
- Feed price
- Reputation of feed manufacturer
- Availability of the feed
- After-sales service
- The opinion of neighbouring farmers

A network of local feed dealers ensures the availability of commercially manufactured aquafeeds throughout all the farming areas. All the major feed manufacturers supply feed to a network of feed dealers who buy feed in bulk from the factories. The dealers are either leading farmers in the area or private entrepreneurs (traders) who sell the feeds to the local farmers. The dealers usually maintain large feed stores from where the feed is distributed to the farmers. These dealers are located in towns close to the farming areas, and within a 10 to 20 kilometre distance from the farms. In some cases, where there is substantial farming activity taking place, they may also be located in villages.

3.2.7 Feed prices and financing arrangements

The price of pelleted feed ranges from US$0.5/kg to US$1.25/kg. The average unit price of the feeds used in extensive, modified extensive and semi-intensive farms are US$0.92, US$1.08/kg and US$1.17/kg, respectively (Figure 5). The feed cost in modified extensive farms contributes 57.5 percent of the total production cost while it is 65.5 percent in the semi-intensive farms (see Table 13).

FIGURE 5
Unit price of shrimp feeds used at different stocking densities



Source: Field survey (2010).

The feed price varies depending on the percentage of protein in the feed (Table 7) and the reputation of the feed manufacturer. A comparison of the average FCR and feed prices of the formulations used at different stocking densities (Figure 6) demonstrates that with an increase in stocking density there is an increase in both FCR and feed price. Many farmers prefer to keep production costs low, and by using low inputs in low stocking density systems they can use low protein feeds. In these systems, natural pond productivity assists in maintaining acceptable FCR.

TABLE 7

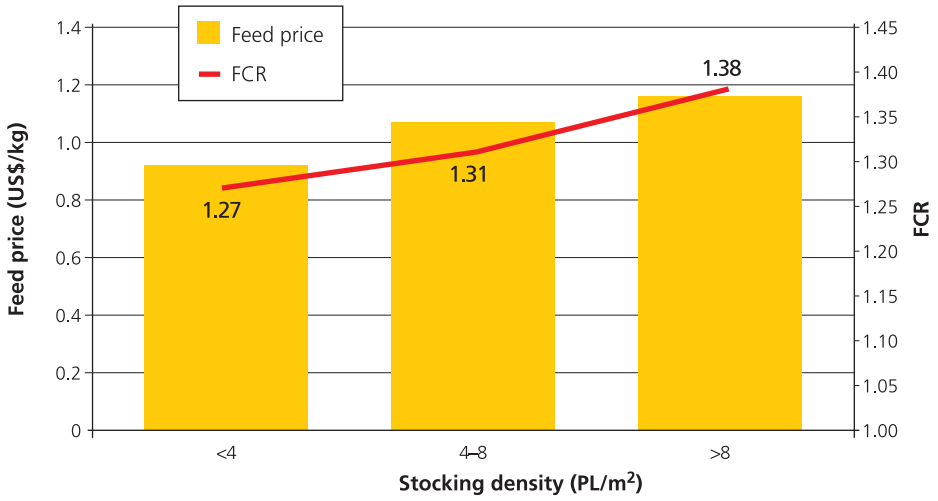
Average prices of feed containing different protein levels (data sourced from different feed manufacturers)

Protein content (%)	Average feed cost	
	INR/kg	US$/kg
30	30.50	0.64
32	30.67	0.64
36	51.83	1.09
38	54.68	1.15
40	49.40	1.04
42	54.75	1.15
44	62.00	1.30

Source: Field survey (2010).

FIGURE 6

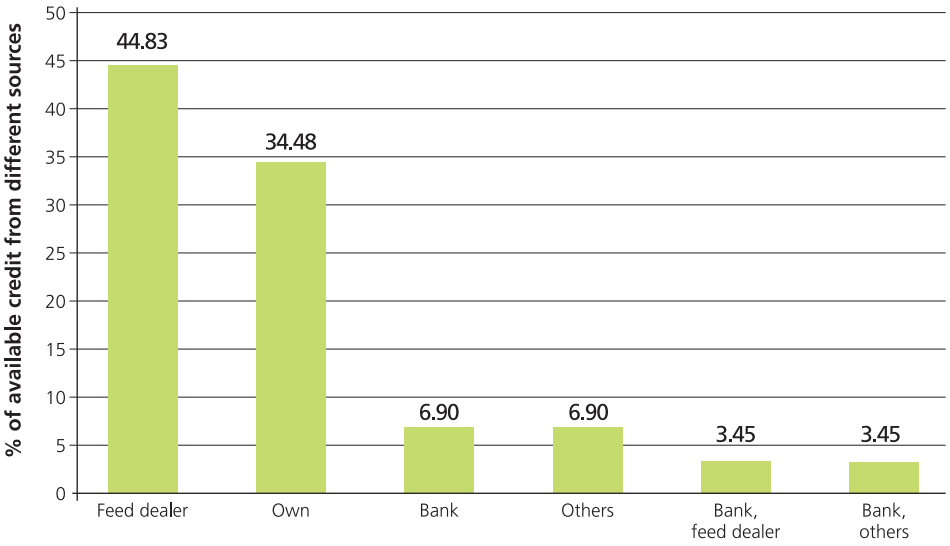
Average FCR and prices of feeds used at different stocking densities



Source: Field survey (2010).

Of the farmers surveyed, 45 percent purchase feed on credit from the feed dealers, 34 percent invest their personal savings, and the rest obtain their capital from banks and other financial institutions (Figure 7). Farmers have to pay the Maximum Retail Price (MRP) that is set by the feed manufacturers for those feeds that are purchased on credit. For those farmers who purchase with cash, the cost of the feed is reduced by 10 to 15 percent – depending on the quantity that the farmers purchase.

FIGURE 7
Available credit sources for shrimp farming in India



Source: Field survey (2010).

3.2.8 Feed transportation and storage

Farmers who purchase their feeds in bulk from feed dealers take responsibility for its transport to their farms. This is achieved by either hiring a truck or an auto rickshaw (small three-wheeler vehicle) (Figure 8). Small farmers who buy one or two feed bags at a time transport the feed on a bicycle/motorcycle (Figure 8). Farmers purchase enough feed to last for one or two weeks, and replenish the feed stock as and when required. Feed is stored in feed stores. Small farmers who do not have feed storage facilities at the farm site store their feed in their homes (Figure 9). Feed transportation and distribution is schematically presented in Figure 10.

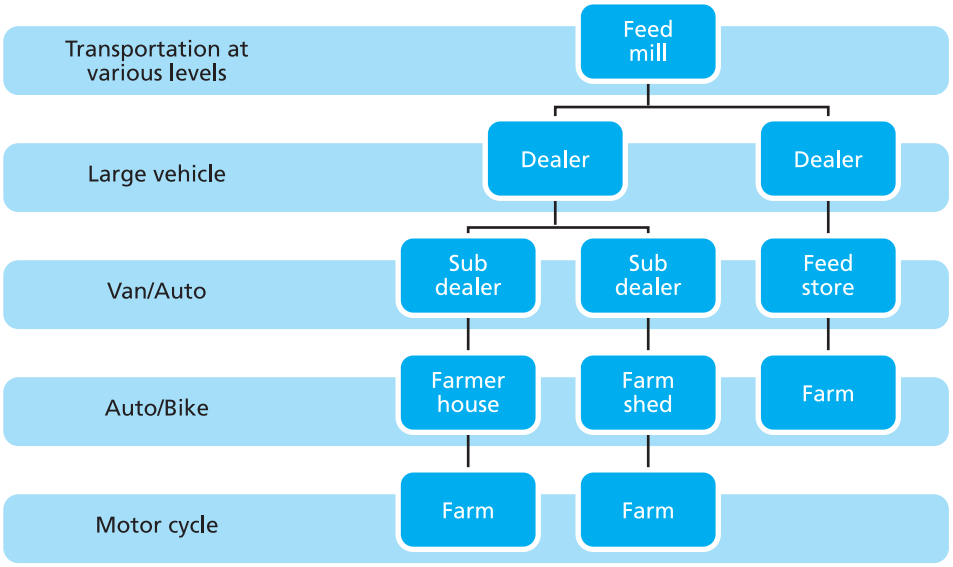
FIGURE 8
Transportation of feed by an auto rickshaw (left) and motorcycle (right)

COURTESY OF FAO/UMESH N. RAMASWAMY.

FIGURE 9
Storage of aquafeed: feed store of a feed dealer (left) and feed storage at the farm site (right)

COURTESY OF FAO/UMESH N. RAMASWAMY.

FIGURE 10
Schematic representation of feed transportation and distribution



Source: Field survey (2010).

3.2.9 Feed management practices

Successful shrimp farming is dependent on providing both good nutrition and maintaining good feed management practices. Feed management strategies must take into consideration several parameters, including the physiological processes that affect feed intake and digestion. They should be designed such that they promote optimal growth, feed conversion, reduce pollution and ultimately minimize feed costs (Molina, 2009).

The optimal feeding rate and frequency are determined at each farm and for different feeds by testing and comparing results in growth, survival and feed efficiency trials over several growth cycles. Farmers calculate feed rations based on the population size and biomass, survival estimates and the size distribution of the culture stock. Shrimp are benthic feeders, and it is difficult to estimate feed consumption rates unless check trays are used. Trays are currently one of the common options used by farmers to manage and adjust feed rations and prevent under- and over-feeding. Thirty days after stocking, farmers use feeding trays to monitor feed consumption. These enable them to adjust the

daily ration according to apparent feed consumption. In addition, it allows for a quick health status check. Two to four check trays are installed in each pond for monitoring animal health and feed intake. The observations that are critical to the effective use of the check trays include the amount of feed remaining after the feed round, the number of shrimp on the tray, and the size of the shrimp. A standard feed table is applied to feed management. Under this system the rations are based on the size of the shrimp that are recorded during the weekly sampling. The amount of feed in that is placed in the check tray is based on a standard table (Table 8) or the experience of the farmer. The check tray factor provides an indication of the percentage of the ration that should be placed in the check tray for the following feeding. For example, if 10 kg of feed is the calculated amount to be fed to shrimp (with a mean weight of 10 g), and the amount remaining on the check tray from the previous feeding is 2.2 per cent (Table 8), the actual amount to be placed in the tray at the next feeding time should be reduced by 2.2 percent, namely to 9.78 kg (Figure 11). This amount would be divided evenly between all of the trays in the pond. The checking period provides an indication of the number of hours after feeding when the trays should be inspected. As the shrimp grow in size and the amount of feed required increases, the time delay between feeding and tray inspection is reduced from 2 hours post-feeding to 1½ hours (Figure 12).

Check trays are circular or rectangular and are made of iron/steel or PVC, and cost about US$2.50 to US$5.00. They are used after one month of stocking and placed on the bottom of the ponds in at least two to four locations, and between 3 to 4 m from the levees. In most cases catwalks are constructed to allow access to the check trays. From 45 days of onwards, the quantity of uneaten feed remaining on these trays is used to calculate the feed rations, as indicated in the previous paragraph. In ponds that have variable cohorts of shrimp at various sizes, farmers mix pellet sizes to ensure that all of the shrimp have access to the feed – if the feed is too big, the smaller shrimp may not be able to feed optimally and their growth rate will be reduced.

TABLE 8
Feeding regime for shrimp farming

Age (days)	Mean body weight (g)	Feed given per day (% of total shrimp biomass)	% feed remaining in check trays	Time of check tray observation after feeding (hours)
1–20	PL15–1.0	20.0–5.0		
20–35	1.0–4.0	5.0–4.0		
35–50	4–6	6.0–5.0		
50–55	6–7	5.0–4.5	2.0	2.0
55–60	7–8	4.8–4.2	2.0	2.0
60–65	8–9	4.2–4.0	2.1	2.0
65–70	9–11	4.0–3.8	2.2	2.0
70–80	11–14	3.8–3.6	2.3	1.45
80–90	14–17	3.6–3.3	2.4	1.45
90–100	17–21	3.3–3.0	2.5	1.45
100–110	21–25	3.0–2.5	2.7	1.30
110–120	25–30	2.5–2.1	3.0	1.30
120–130	30–36	2.1–1.6	3.5	1.30
130–140	36–43	1.6–1.5	4.0	1.20
140–150	43–50	1.5–1.4	4.5	1.15

Source: Field survey (2010).

FIGURE 11
Weighing feed rations and samples of feed (green bottles) for placing on the feed trays

COURTESY OF FAO/UMESH N. RAMASWAMY.

FIGURE 12
A farmer monitoring a feed tray

COURTESY OF FAO/UMESH N. RAMASWAMY.

Farmers keep complete records of the quantity of feeds applied to each pond. Shrimp are sampled every week after 45 days of culture. Cast nets are used to provide biomass estimates, which are used to adjust feeding rates. Farmers also check the pond bottom for deterioration. A deterioration in pond bottom condition (a blackening of the soil, hydrogen sulphide or ammonia production) could signify excess feeding. In such cases, farmers recheck and adjust the feeding rates accordingly.

The feed rations are adjusted daily, with minor adjustments between feeds that are dependent upon the consumption rates of the shrimp. This practice minimizes feed wastage. As shrimp are effectively scavengers, the most effective way to feed shrimp is to provide small amounts of feed frequently. The number of feed rounds per day is a trade-off between the optimal number of feedings that is ideal for the shrimp, and the labour (and hence cost) of providing these feed rounds. Farmers develop their feeding schedules based on the stocking density and number of days the shrimp have been stocked. During the initial 30 days post-stocking, feed is provided two to three times a day. This is increased to four to five times a day in subsequent months. From 30 days post-stocking, feed rations are adjusted. Ration adjustments are based on feed tray observations and cast net sampling.

The feed ration is roughly divided into four feeds a day of 25 percent, 25 percent, 20 percent and 30 percent, presented at 06.00 hours, 12.00 hours, 1600 hours and 21.00 hours, respectively. At low stocking densities (<4 PL/m^2) the feeding frequency ranges from two to three times a day (Table 9). At stocking densities of more than 4 PL/m^2, the feeding frequency ranges from three times a day for the first 60 days of the culture cycle to five times a day between days 91 and 120. Feed is distributed either by broadcasting (Figure 13) from the pond levee or by using polystyrene floats.

TABLE 9
The feeding schedule used by farmers in study ponds

Culture period (days)	Stocking density (PL/m²)	
	<4	>4
	Feeding frequency (times per day)	
1 to 30	2	3
31 to 60	2	3
61 to 90	3	4
91 to 120	3	5

Source: Field survey (2010).

Inefficient feed management practices commonly include inadequate handling and storage practices at farms – such as storing the feed in a metal container under hot conditions, feed spillage in the stores, and wastage of feed while feeding, particularly when inexperienced workers are used. Ineffective practices often include applying feed at times that are convenient to the farmer (during daylight hours), but not necessarily the optimal feeding time for the shrimp, feeding very close to the levees, and over-feeding as a result of over-estimating survival rates.

FIGURE 13
Feeding by broadcasting from pond levee during first month of rearing

COURTESY OF FAO/UMESH N. RAMASWAMY.

3.2.10 Feed additives

Seventy-five percent of the respondents reported using probiotics and feed additives. The use of these additives was dependent upon stocking densities (Table 10). There is an increase in the use of probiotics and feed additives as the stocking densities increased. No feed additives were used at stocking densities lower than 3-4 PL/m².

TABLE 10
Use and type of feed additives at different stocking densities

Stocking density (PL/m²)	Probiotics/feed additives used	% of ponds in the study
3–4	No feed additives	26.3
5	Feed probiotics	5.1
6	Feed probiotics, vitamin C	11.6
7	Feed probiotics, cod liver oil	13.5
8	Feed probiotics	4.1
9	Feed probiotics, yeast	12.5
10	Feed probiotics, vitamin C	11.6
11	Feed probiotics, vitamin C	15.3

Source: Field survey (2010).

3.2.11 Pellet size

Pellet size is based on the size of the shrimp. Generally, during the first month, a starter feed (0.4 to 1.4 mm crumble) is used. When shrimp reach 4–5 g, the feed is changed to pellets (1.8–2.3 mm diameter). Finisher feed (2.3 mm diameter) is used towards the end of the rearing period when the shrimp reach >20 g. The protein content and feed price varies according to the type of feed (Table 11).

TABLE 11
Specifications and price range of shrimp feeds manufactured in India

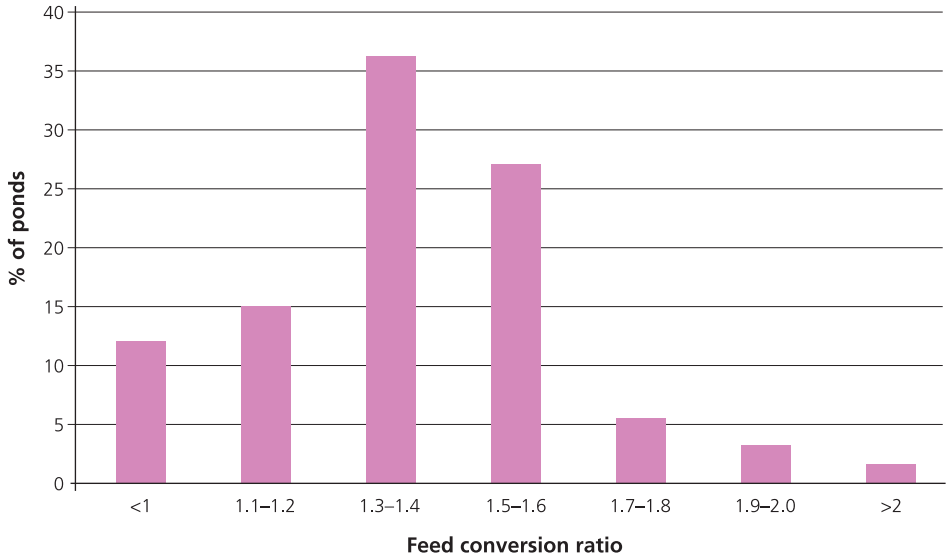
Feed class	Shrimp size (g)	Feed type	Feed size (mm diameter)	Crude protein (%)	Price (US$/tonne)
Starter	0.5–5	Crumble, short cut pellets	0.4–1.8	40–44	1 066–1 450
Grower	5–20	Pellets	1.8–2.3	38–40	959–1 429
Finisher	>20	Pellets	2.3	36–38	853–1 407

Source: Field survey (2010).

3.2.12 Feed conversion ratios (FCR)

All the study farms used commercially produced aquafeeds during the production cycle. These feeds were produced by 9 different manufacturers. Reported FCR ranged from <1:1 to 2.7:1 (Figure 14). The variability was attributed to different production conditions, feed management practices, and production protocols. An FCR below 1.5:1 is considered good by the farmers. About 63 percent of the ponds included in the survey were reported to achieve FCR ranging from 1.2:1 to 1.6:1 (Figure 14) but 1.6 percent had FCR of more than 2:1.

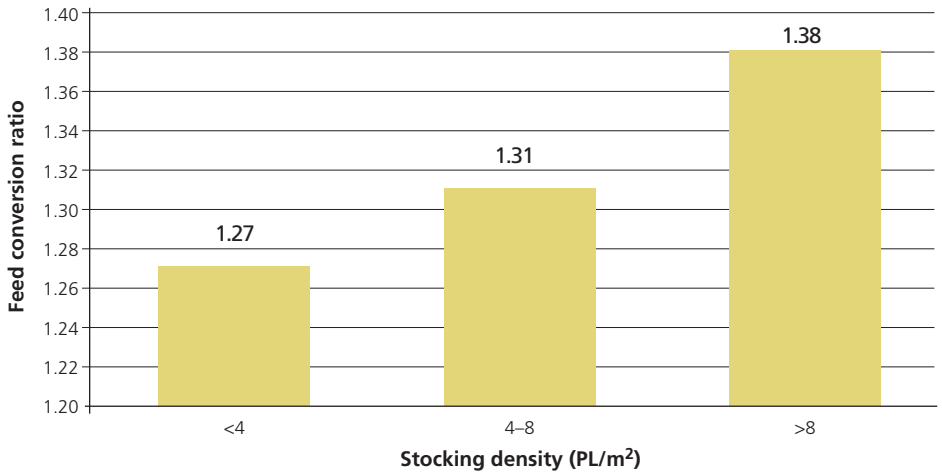
FIGURE 14
Percentage of variation in FCR in study ponds



Source: Field survey (2010).

With respect to stocking densities, the lowest FCR were observed at stocking densities below 4 PL/m² (FCR: 1.27:1, Figure 15). At stocking densities of 4–8 PL/m², the mean FCR was 1.31:1, and at 8 PL/m², the mean FCR was 1.38:1.

FIGURE 15
Variation in mean FCR in study ponds



Source: Field survey (2010).

3.2.13 Productivity

The survey revealed that the yields attained using the extensive farming systems ranged between 146 and 510 kg/ha/crop (Table 12). In modified extensive farming systems, they ranged from 870 to 1 656 kg/ha/crop. The yield in the semi-intensive farming systems ranged from 1 783–4 178 kg/ha/crop. In traditional farms (*Bheris*), yields ranged from 200–350 kg/ha during the crop period, with an average size range of 30–40 g shrimp being produced. Finfish are also harvested throughout the crop period in these *Bheri* systems.

TABLE 12
Stocking density and average yield per hectare

Stocking density (PL/m²)	Mean level of production (kg/ha/crop)
Extensive farming system	
1	145.7
2	488.9
3	510.3
Modified extensive farming system	
4	870.7
5	1 349.3
6	1 424.2
7	1 655.6
Semi-intensive farming system	
8	1 783.3
9	2 518.4
10	2 729.6
11	3 186.0
12	3 279.4
13	2 908.3
14	3 409.1
15	1 516.0
17	4 177.8

Source: Field survey (2010).

3.2.14 Cost-benefit analysis

Shrimp farming depends largely upon the use of commercially formulated high-energy feeds. Commercially produced pelleted feeds are provided in most of the extensive farms (<40 000 PL/m²), all of the modified extensive farms (40 000–80 000 PL/m²) and all of the semi-intensive farms (>80 000 PL/m²); feed comprises 47.7 percent, 57.5 percent and 65.6 percent of the total operational costs respectively (Table 13). The second highest expense is for the fuel/energy that is required for pumping, pond filling, water exchange and aeration. The fuel/energy cost per unit of shrimp produced in extensive, modified extensive and semi-intensive farms are US$0.54/kg, US$0.56/kg and US$0.36/kg, respectively. The total expenditure was lowest in the modified extensive system (US$3.53/kg), while it was US$3.54/kg and US$3.89/kg in extensive and semi-intensive farming systems respectively. The profit margin per kilogram of shrimp production was highest at US$1.58/kg in the extensive farming system, followed by the modified extensive system (US$1.11/kg). The lowest profit margin was in semi-intensive farming system (US$0.53/kg).

TABLE 13

Summary of average production costs (US$/kg shrimp produced) at different stocking densities

		Stocking density (number/ha)		
	Totals	**<40 000**	**40 000–80 000**	**>80 000**
No. of ponds	183	59	68	56
Pre-stocking				
Pond preparation (drying + sludge removal + ploughing)	0.17	0.28	0.17	0.14
First water filling	0.06	0.11	0.07	0.05
Total pre-stocking expenses	0.23	0.39	0.24	0.19
Seed (including PCR and transportation)	0.44	0.62	0.35	0.41
Post-stocking				
Feed	2.37	1.69	2.03	2.55
Water exchange	0.33	0.39	0.42	0.15
Aeration	0.12	0.04	0.07	0.16
Feed additives	0.06	0.05	0.04	0.08
Chemicals	0.17	0.08	0.17	0.18
Agri lime	0.10	0.14	0.11	0.08
Total post-stocking expenses	3.15	2.39	2.84	3.20
Others				
a. Labour	0.09	0.13	0.09	0.08
b. Miscellaneous	0.01	0.01	0.01	0.01
Total other expenses	0.10	0.14	0.10	0.09
Total expenditure	3.92	3.54	3.53	3.89
Revenue	4.50	5.12	4.64	4.42
Profit	0.58	1.58	1.11	0.53

Source: Field survey (2010).

4. DISCUSSION

A feed management plan is designed to maximize growth, survival, total production and mean animal size, optimize feed conversion ratios (FCR), and minimize environmental impacts. More specific goals include providing the animals with a feed of the highest quality in the most cost-efficient way, and supporting the highest growth and production possible (Jory *et al.*, 2001). Farmers monitor and continuously adjust their feed rations according to changes in consumption rates that are caused by environmental variables, and the moulting cycle of the shrimp. Farmers always aim to minimize overfeeding, and its concomitant negative effect on production costs and the culture environment.

4.1 Feed selection

The modified extensive and semi-intensive farmers overwhelmingly indicated that they prefer to use manufactured feeds. The economics of using manufactured feeds combined with the low levels of pollution associated with their use and the concomitant reduction in costs associated with maintaining water quality, managing disease, and facilitating higher stocking densities and yields were seen as key advantages of their use. In addition, using these feeds also leads to a reduction in labour costs in terms of feed procurement, storage, preparation and administration.

Farmers select their formulated feeds to meet several criteria, including pellet size, uniformity of appearance, physical integrity, density, moisture, protein and lipid content, water stability, appearance and smell. The feed must fulfil the known nutritional requirements of the target species, be fresh and free of mycotoxins and pesticides, and have a low pollution potential. The feed should have attractants (natural or synthetic) to improve feed palatability and stimulate consumption (ASEAN, 2005). The feed must be water- stable, minimizing nutrient losses and wastage. Poor quality aquafeeds may leach nutrients rapidly after immersion, and thus it is important that feeds remain attractive to the target animal and maintain their form after immersion in water – this will maximise consumption rates, nutrient ingestion, and minimize wastage (Jory *et al.*, 2001).

When assessing the quality of their feeds, the farmers surveyed used the following criteria:

- ***Feed quality:*** Feed quality is the key criteria on which farmers make their purchasing decisions (pellet size, uniformity of appearance, physical integrity water, stability and smell).
- ***Previous experience:*** Farmers select their feeds based on their previous experiences and the resultant crop.
- ***Feed price:*** Extensive farmers tend to select lower protein (30 to 34 percent CP) low-cost feeds (US$0.63/kg). In contrast, the semi intensive farmers tend to select higher protein (36 to 40 percent CP), higher quality, more expensive feeds (US$1.05/kg).
- ***The reputation of feed manufacturer:*** The reputation of the feed manufacturer for supplying good quality feed consistently is an important consideration. Farmers cited examples where some manufacturers supplied good quality feed during the initial days of launching the feed. However, latterly there was a decline in its quality, which was reflected in poor growth and FCR. Farmers tend to experiment with different feeds from different manufacturers, and finally settle for one feed type that promotes good growth and an economical FCR.
- ***Availability of the feed:*** Feeds must be available to the farmers, and supply shortages result in farmers switching to alternative feeds.
- ***The opinions of other farmers:*** The farmers who are new to shrimp farming tend to take advice from neighbouring farmers about their experience with different feeds; they often decide which feed to use in their farms based on this information.

Farmers do not usually change feeds unless they encounter problems, such as poor growth rates, poor water stability or increased feed costs.

4.2 Feed cost and finance

Of the farmers surveyed, only 42 percent purchased their feed by paying cash. The others purchased their feed on credit. At present, there are no financial institutions that support the shrimp farmers. Access to institutional finance can reduce feed costs by 10 to 15 percent, and providing appropriate financial services is an area that needs to be addressed by the authorities. In many cases, farmers purchasing feed on credit are linked into buy-back agreements for their shrimp. In such cases, the farmers cannot sell the shrimp directly to processors/exporters, resulting in lower prices to the farmers.

The average feed price increases as the stocking density increase. This increase in price is related to the increase in the feed protein content as the density increases, which varies from 30 to 44 percent. The highest protein formulations are used during the first month of the production cycle, and the crop is subsequently changed onto to lower protein formulations. Those ponds that are fed with high protein feed during the initial stages of the culture period elicited good FCR, even when the percent protein decreased during last month of the grow-out phase. Those ponds which were fed with low protein formulations during the initial phase exhibited comparatively poorer FCR.

4.3 Feed transportation and storage

Appropriate feed handling and storage have immediate and significant consequences for shrimp production. The poor storage and handling of feeds results in product deterioration, increased fines, reduced feed attractability and palatability, possible nutritional deficiencies and disease outbreaks, and reduced growth rates and production (Jory *et al.,* 2001). Feed transportation employs a network of feed dealers who source the feed directly from the feed manufacturers in trucks, and store them in their warehouses. These warehouses are not air-conditioned.

4.4 Feed additives

In addition to the nutrients provided in the feed, farmers frequently top-dress their feeds with vitamins, minerals, immunostimulants, fish oil, probiotic bacteria and yeast, vitamin C and egg albumin. These feed additives are perceived by the farmers to be feed attractants and growth promoters (Hasan *et al.,* 2007). While some farmers top-dress all the feed that they use, many farmers top-dress their feeds only during specific phases of the culture period, when they feel that shrimp growth rates are slowing down or the culture environment is becoming unfavourable. No evaluation of the efficacy of top-dressing has been undertaken. Nevertheless, some preliminary investigations reveal that most water-soluble vitamins and minerals are lost when they are applied to the feeds. The study demonstrated that top-dressing typically increased feed costs by US$39/tonne.

4.5 Feed management and optimizing feed conversion ratios

Feed management is a critical aspect for cost-efficient, environmentally responsible shrimp production. Appropriate feed management practices maximize shrimp growth and survival, while reducing feed inputs and minimizing effluent streams. Poor feed management will lead to sub-optimal production, may promote the onset of various diseases and water quality related problems, and may adversely affect production (Jory *et al.,* 2001). During the 1990s, farmers generally fed during the night; shrimp tend to be most active then, showing peaks in feeding behaviour during the night and just before sunrise (Jory *et al.,* 2001) At high survival rates or when the biomass of the shrimp in the pond is high, these authors found that it was less important to feed at night, and thus many farmers started feeding at similar levels throughout the day.

Shrimp ponds are complex environments, where feed input is just one of the factors affecting yields. The generation of natural feeds through fertilizer use and the enhancement of natural pond productivity is of greater production importance at low stocking densities. Under semi-intensive culture, most, if not all, of the nutrients required for growth must be provided by formulated feeds. An important reason for the good FCR reported in this study is the promotion of beneficial bacteria in their culture ponds. Beneficial *in-situ* bacterial populations are promoted by regular mild stirring of the pond bottom using iron chains to suspend the organic matter. This is followed by the addition of a carbon source (molasses or a fermented mixture of molasses, rice powder and yeast) at 50 litres per ha to increase the C : N ratio in the pond. This practice is repeated every week after one month from stocking; it is economical and found to be useful in extensive and modified extensive farms (<8 PL/m^2). This observaion is supported by the trend of increasing FCR with increasing stocking density. Semi-intensive farms (>8 PL/m^2) tend to use commercially available probiotic preparations, which are supplied by the feed manufacturers and other retailers. This shift towards the promotion of heterotrophic bacteria in all three kinds of shrimp ponds could be one of the reasons why the farmers in the study ponds attained good FCR.

The FCR reported in this study demonstrate the positive impact of promoting better management practices in the sector. It was evident that with the use of good quality feeds and good feed management practices, FCR of 1.2:1 to 1.4:1 can be achieved. By improving feed management practices further, there would be scope to further reduce the FCR in extensive farms to below 1.2:1, and in modified-extensive and semi-intensive farms to below 1.4:1.

As feed intake patterns and consumption rates for shrimp vary under different agro-climatic conditions, a site-specific standardized feeding programme is essential for effective feed management. From the current study it is evident that both feed quality and feed management practices play an important role in governing production and feed conversion efficiencies, as well as minimizing pond bottom and water quality deterioration due to over- or under-feeding. Ration sizes need to take into consideration the environmental status of the pond waters, which varies on a seasonal basis, and the biomass in the pond. Maximum benefits from supplemental feeding can only achieved if the diet is ingested in its entirety, and supplied at a rate that is compatible with the quantity and quality of natural food available in the pond (Hasan *et al.*, 2007).

4.6 Development trends

The following developmental trends were observed in this study:

- An increase in the use of high quality seed and SPF seed from improved broodstock resources.
- An improvement in the sustainable, effective, and optimal use of water resources.
- A trend towards intensification.
- The application of Better Management Practices (BMP) to reduce the cost of production, and to fulfil the market requirement through organized farmer groups.

4.6.1 Stocking high quality seed and SPF seed from improved broodstock resources

The excessive reliance on wild broodstock poses problems in terms of the sustainability of the natural resource and ecosystem function. Moreover, the procurement of wild broodstock is becoming commercially unsustainable as increasing numbers of consumers from developed countries insist that their shrimp supply is derived from sustainable sources. In the coming years, the market will likely require that seed be obtained from domesticated Specific Pathogen Free (SPF) stock. The use of wild

broodstock also poses serious risks for vertical disease transmission from the breeders to the offspring, and it is for this reason that viral diseases must be controlled at the broodstock level (Hoa, 2009). Indian shrimp hatcheries are totally dependent upon wild-caught gravid females. The high infection rates of the wild-caught broodstock with pathogenic viruses and bacteria lead to poor quality seed, diseases and stock losses in the hatcheries and farms. In India, data has shown that unhealthy and infected PL lead to frequent crop failures, with estimated losses of up to US$110–220 million per annum (FAO, 2007).

The availability and supply of high quality broodstock is vital to successful shrimp hatchery operations, and the production of high quality PL that can support the grow-out sector. With the emergence of a series of serious shrimp pathogens, disease-free wild broodstock have become rare around the Indian coast and across all other Asian countries. As a result, extreme care must be given to the collection, transportation, handling and maintenance of broodstock that are free of these pathogens, and to the biosecurity of the hatchery produced PL.

Disease free, good quality seed is the key to sustainable *P. monodon* aquaculture. Many countries in Asia are attempting to supply their farmers with SPF seed. Several research institutes and private companies have been involved in these developments. These include Aquacop in Tahiti (French Polynesia), the Southeast Asian Fisheries Development Center (SEAFDEC) in the Philippines, the National Center for Genetic Engineering and Biotechnology in Thailand, the Department of Fisheries of Malaysia, a commercial programme by a French group at Aqualma from Madagascar, a research programme by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia, and a commercial project by Moana Technologies Inc, which was founded in Belgium and operates from Hawaii (Hoa, 2009).

The successful domestication of black tiger shrimp will ensure that sufficient quantities of good quality broodstock are available and, as a consequence, reliable seed production will be possible. Recently an Australian company reported that after eight generations of selective breeding, the Commonwealth Scientific and Industrial Research Organization (CSIRO) scientists and the Australian aquaculture industry have bred black tiger shrimp that produce record yields. One of the CSIRO partners, Gold Coast Marine Aquaculture, produced average yields of 17.5 tonnes per hectare, more than double the industry average. Several ponds produced 20 tonnes/ha and one produced a record yield of 24.2 tonnes/ha (www.seafoodsource.com).

In 2008, an agreement was signed between the National Fisheries Development Board of India and M/S Moana Technologies, Hong Kong to produce and supply genetically improved SPF shrimp. At full capacity, it is anticipated that the programme will produce approximately three billion PL per annum. This programme heralds a new approach to quality seed management, enhanced productivity and profitability in Indian aquaculture. Similarly, the Rajiv Gandhi Centre for Aquaculture (RGCA) of MPEDA is running a project in Andaman to produce SPF seed; this programme is expected to begin producing results by 2013.

The development of reliable domesticated broodstock to produce high quality and SPF seed represents an important development in the long-term sustainable development of *P. monodon* aquaculture. It will also assist in protecting natural resources of wild black tiger shrimp from over-fishing.

4.6.2 Sustainable, effective, optimal use of water resources

Production technologies are improving and systems requiring less water exchange are being adopted by the farmers. These systems require increased aeration, and improved water quality management that enhance beneficial bacteria in the ponds. To reduce input waters, minimal water exchange is now the preferred option. This reduces the risks associated with disease introduction and improves biosecurity at the farm level.

The system involves filling the pond with screened and chlorinated brackishwater/seawater. The shrimp are stocked and cultured for a period 120 days, attaining an average weight of 25–30 g. The system does not depend on frequent water exchange but simply maintains the water level in the pond by replacing water losses due to evaporation and seepage with screened/chlorinated seawater or brackishwater. Water exchange is only carried out in the event that water quality deteriorates, and when there are no disease outbreaks in the vicinity of the farm. In addition, ponds are being made deeper to increase their production capacities. Farmers are also reducing their use of antibiotics and chemicals, and are shifting their focus towards probiotic culture.

This trend towards increased intensification and productivity means that extensive and modified extensive farms are increasingly being converted to semi-intensive farms. The increased intensification requires well designed grow-out facilities. Typically, ponds are much smaller (0.1 to 1.0 ha) with increased depths (1.5-2.0 m). Water exchange is limited and stocking densities range from 100 000 to >200 000 PL per hectare. It is possible to produce two crops per year with output levels of 3–5 tonnes/ha/crop. Nutritionally complete artificial feeds, increased aeration and intensive monitoring are required for this type of farming system.

4.6.3 The adoption of farmer groups and the application of better management plans (BMP) and good aquaculture practices (GAP)

Small-scale shrimp farmers in India, Indonesia, Bangladesh and Viet Nam are increasingly becoming organised into groups or clusters. These promote economies of scale through collective bargaining, and their members have access to BMP/GAP that are designed to improve feed management. Grouping and clustering farmers is also used to encourage the farmers to address market requirements and gain access to international markets. This is often achieved through the promotion of private standards for food safety and quality, animal health, environmental sustainability and social responsibility, and the adoption of eco-labelling. The certification of shrimp aquaculture may become the norm in the very near future. Under such a scenario, the farmer groups will be able to attain cluster certification through the implementation of GAP and Internal Control Systems (ICS) which will reduce the costs of certification and help them meet future market requirements.

4.7 Key issues and recommendations

The major constraint to the use of commercially manufactured aquafeeds is their high cost. The increasing trend in feed prices is not reflected in increasing crop value, and thus the profits from many farming operations are increasingly being eroded. To remain profitable, feed utilization needs to become more efficient and, wherever possible, cheaper feeds will have to be adopted. To ensure the long term sustainability of the sector, there are five focus areas that require attention. These comprise:

- Improved capacity building and management through the clustering of small-scale shrimp farmers.
- The promotion of ‘on-farm feed management practices’.
- A reduction in feed and feed ingredient costs.
- Ensuring that research is effectively translated into commercial realities.
- Improvements in the policy and regulatory environment

4.7.1 Improved capacity building and management through the clustering of small-scale shrimp farmers

While large scale farming operations have a high degree of control over input costs, smaller operations lack the critical mass required to exercise any meaningful degree of control over them. The relatively high input costs associated with small-scale farming activities inherently increase the financial risks associated with the farming operations.

This risk can be reduced if farms are clustered or if farmers organize themselves into groups (Hasan *et al.,* 2007). It should be recognized that the majority of the farmers operate at the household level and have relatively limited education, and thus the transfer of complex technical messages is problematic and requires continuous attention (Hasan *et al.,* 2007). As a component of a farmer level capacity building programme, NaCSA (National Centre for Sustainable Aquaculture) in India has facilitated the organisation of 16 760 small-scale shrimp farmers into 772 registered aquaculture societies (NaCSA, 2011). Each society comprises a group of 20 to 30 farmers in a farming cluster. This has enabled farmers to access information more effectively, and promotes training within the group.

4.7.2 Promotion of 'on-farm feed management practices'

There is a need to promote improved farm management practices, including the efficient use of feeds. The industry is developing rapidly and farmers need to keep abreast of new technologies and developments. Failure to do so will lead to greater inefficiencies (Hasan *et al.,* 2007). Farmer clusters provide a good opportunity for the rapid and efficient dissemination of good on-farm feed management practices; these in turn help to reduce production costs. Feed management guidelines for shrimp have been developed by NaCSA (NaCSA/MPEDA, 2013) and are outlined in Annex 1.

Black tiger shrimp culture is moving towards further intensification, and formulated feeds will play an increasingly important role in the long-term sustainability of the sector. Detailed studies are required to establish current feed utilisation and management practices in all the shrimp culture systems, and to develop recommendations to improve feed utilization and management practices. In addition, shrimp feeds are made of highly perishable ingredients, and it is important that farmers are taught to handle and store them appropriately.

4.7.3 Efforts to reduce the cost of feed and feed ingredients

The primary and immediate goal should be to address the high costs associated with shrimp feeds. This can be achieved by focusing on the following issues:

- The nutritive value of locally available ingredients such as soybean meal, fishmeal, fish oil and shrimp meal could be improved by upgrading local manufacturing processes. Policy-level initiatives such as providing technological assistance and incentives for ingredient processors could assist in this process.
- Feeds and feeding strategies based on feed ingredient sources from agriculture and fishery by-products/wastes need to be developed (Hasan, 2001).
- Access to finance – a significant constraint to small- and medium-scale farmers in managing the cost of feed and the lack of affordable credit. Efforts to improve access to credit should be made by the central and state government agencies.
- Improvements to traceability protocols within the shrimp production cycle need to be made. These interventions should also be included in feed manufacturing processes.
- Fishmeal replacements need to be included in shrimp feeds – Asia is a net importer and the largest global user of fishmeal and fish oil. It is therefore not immune to global issues in respect of fishmeal and fish oil use in aquafeeds. Although many studies have been undertaken to identify dietary protein sources that can act as fishmeal replacements, the results are rarely translated into practice, and there is a need to establish an effective dialogue between researchers and the feed industry. Throughout the region there are growing concerns with regard to feed quality, and consequently suitable guidelines and certification processes need to be introduced (De Silva and Hasan, 2007).
- It is likely that the formulations used in the commercial production of shrimp feeds have higher nutrient inclusion levels than required – especially those

feeds used in extensive and modified extensive systems. The results of the study demonstrate that there is little difference in the protein content of feeds used at stocking densities of 4 to 8 PL/m² and >8 PL/m². There is a need to reduce feed costs at lower stocking densities by reducing the protein and other nutrient levels, and increasing the nutritional contribution from natural food productivity.

- There is a need to study the impact of storing feed in air-conditioned or non air-conditioned stores, and to determine how storage conditions affect shrimp growth, FCR and other production indices.

4.7.4 Ensuring that research is effectively translated into commercial realities

There is a need to partner publicly funded research with the commercial feed manufacturing sector. Such an intervention could be used to promote the development of better feed standards and allow research results to be more effectively transferred to farmers (Hasan *et al.*, 2007). Feed management research is required to improve feed utilization indices and reduce the feed costs. The Central Institute of Brackishwater Aquaculture (CIBA) in India has developed low-cost feed formulae for shrimp, and close collaboration with the feed manufacturing industry is required to commercialize these feeds.

The role of natural pond productivity, particularly the heterotrophic bacteria, in the nutritional budget of the shrimp needs to be established, and the use of improved pond fertilization, substrate enhancement, water and pond bottom management techniques promoted. There is a need to assess the protein requirements of shrimp at different stocking densities, and to establish the efficacy of the feed additives that are commonly applied to the feeds.

4.8 Conclusion

The development and use of manufactured feeds has been a major factor in the successful expansion of *P. monodon* farming. Feed contributes 48 to 67 percent of the production costs, and it is important that efficient on-farm feed management strategies are developed to improve the economic efficiency of the farming operations. In this regard, better feed management practices are needed to maintain and improve the financial and environmental viability of the culture systems. Sustainable interventions are necessary to accelerate the growth in the sector.

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ANNEX 1
NaCSA feed management guidelines for shrimp

1. Feed storage guidelines

1. Feed should be stored in clean, cool and ventilated area, well protected from sunlight
2. Bags must be stacked neatly on pallets away from walls to prevent feed from being in direct contact with damp floor.
3. Farmers are advised to avoid excessive handling of feed bags, and to handle with care.
4. Different types of feeds must be kept separate and clearly demarcated.
5. Feed stock must be rotated using older feed first, feed that has been stored the longest. 'First in, first out' principle must be followed. Feed should not be stored for more than 2–3 months.
6. Precautions must be taken to prevent the entry of animals through doors and windows to the storage areas. This can be achieved by blocking with entrances with meshes. Stores must be kept clean.
7. Fuel items should not be stored in the feed store.
8. On farms that feed several times in a day, the total feed ration is transported from the warehouse to the ponds once, usually early in the morning. In such cases, feed bags should be protected from sunlight and rain, by storing them off the ground in simple, pond side storage sheds.
9. During the rain, proper care should be taken to prevent feed bags getting moist by ensuring there is no leakage in to the feed store and covering the feed bags with an extra layer of plastic cover.
10. Empty feed bags may be used as a cover over farm sheds or sold to local traders who recycle them for other purposes.

2. Feed management guidelines

1. Date of manufacture on the feed bag should be checked upon its arrival. Farmers should ensure that the feed is not more than 90 days old form date of manufacture. Farmers should not use feed older than 90 days, if found to be older than 90 days, it should be returned back to feed dealers.
2. Shrimp should be fed from the day stocking. The starter feed (crumble) should be mixed with a little water to distribute easily and ensure that it sinks rapidly.
3. Appropriate pellet sizes should be determined based on the size of the shrimp. A mix of two feed sizes should be used for at least 4 days while switching from one feed size to the next.
4. The feed fed on daily basis should not exceed the quantity that is indicated in the feed scheme provided in NaCSA BMP manual (Annex 2. The feed quantity to be given should be recorded accurately in the pond record book.
5. Feeding should be reduced during periods of low dissolved oxygen, plankton crash, rainfall, moulting, and extremes of temperature when feed consumption normally reduces.
6. When active swimming of shrimp are observed around the edge of the pond during daylight hours (but not at the water surface) it could indicate under feeding. If this is observed consistently, the feeding rate should be checked and increased accordingly.
7. Check trays should be installed from 30 days onwards for monitoring the feeding.
8. Regular sampling of shrimps should be done once a week after 45 days to determine growth rate and to calculate the FCR.
9. Slightly underfeeding is preferable to overfeeding, this saves money, maintains water quality, and reduces pond pollution.
10. Antibiotics should not be mixed with the feed. Ensure the feed is fresh and of a good quality so that there is no need to add additives.

3. Better feed distribution practices

Different feeding methods are used to deliver feed. The most common method is through broadcasting feeding (by hand) from pond levees, and in the middle of the pond where ropes are tied a few meters inside the pond, parallel to pond levees, and feed is broadcast with the help of floating device (small feeding boat, thermocol or large tube) which helps to disperse the feed uniformly over the pond surface.

1. During the first 30 days of culture, feed should be spread within 2 to 4 m from the edge of the pond as the smaller juveniles prefer shallower areas of pond slope.
2. The normal practice is to spread feed by hand. A simple plastic hand scoop can be used, which helps promote a wider distribution of the feed.
3. After the first month, the feed should be spread all over the pond using a boat/ floating device as the shrimp move in to the inner part of the pond.
4. Pond bottom soil should be checked on a regular basis and feeding should be avoided in areas with black and badly smelling soil (hydrogen sulphide) and in pond corners. Feed is supplied to clean areas in the pond.
5. In the ponds with aerators, feeding is should be done in the areas cleaned by the water movement. Aerators should be switched off just before feeding until 1 to 2 hours after feeding to prevent feed being carried away by the water current.

4. Check tray monitoring guidelines

1. Use 4 check trays (round shape with 80 cm diameter or square of 0.64 m^2) per ha pond to monitor the feed consumption from day 30 of the culture period.
2. Check trays should be placed on the pond bottom 2 m away from the slope of the pond banks, aerators, sluice gates and pond corners.
3. Feed should be provided in check trays and checked as per the feed chart (Table 11).
4. The check tray should be released slowly in to the water to prevent the feed from dispersing and to ensure that check tray settles on the pond bottom by pulling up the check tray few cm when it reach the bottom and again dropping it down.
5. If more than 25 percent of feed remains on the tray, the feed quantity should be decreased by 50 percent for the next feeding; if less than 10 percent of the feed remains on the tray, feeding is continued as scheduled. If no feed is found remaining in the trays the feed should be increased approximately 5 to 10 percent for the next feeding. Feeding should be suspended when farmers find most of the feed provided in the tray is left uneaten in all check trays.
6. There are several factors, other than survival which affect feed consumption in trays; when the reduction in feed consumption is noticed farmers should check for:
   - Deteriorating water quality and pond bottom;
   - Competitors in the pond;
   - Quality of the feed;
   - Moulting cycle;
   - Temperature, salinity and rainfall;
   - Diseases; and
   - Corrective actions should be taken based on these observations.
7. When feed consumption drops dramatically and does not improve within two to three days, the shrimp should be checked for health problems.
8. After check tray observation, check trays must be kept clean and dry.
9. Feed brand, type and quantities must be recorded in the pond record book.
10. Gut content, colour of the shrimp or of its faeces in the check tray should also be examined and corrective actions should be taken (Table A1).

TABLE A1

Gut colour content observation

Gut content colour	Probable food item	Probable cause(s)	Corrective action
Black Dark brown	Benthic detritus, sediment	Under feeding; inadequate feeding frequency	Increase feeding and frequency
Red Pinkish	Cannibalized body parts from dead shrimp	Disease event in pond	Check for dead shrimp in the pond
Green	Benthic algae	Under feeding	Increase feeding
Pale Whitish	Manufactured feed or natural food	Gut infection	Reduce feeding
Golden Brown	Manufactured feed	Normal	-

In addition to the above recommended practices farmers should be provided with a quick chart to trouble shoot any problems with feed management (Table A2).

TABLE A2

Common problems and solutions in shrimp feeding

Observation	Detailed observation	Action required
Shrimp not feeding in the feed net	• Shrimp not yet used to feeding in net	• Use feed nets from 20 days after stocking
	• Over feeding	• Reduce the feed by 50 percent and re-calculate survival
	• Wrong positioning of check tray	• Check the pond bottom near check tray
	• Deterioration in the water quality	• Improve the water quality (pH and DO)
	• Disease outbreak	• Examine shrimp from cast net for signs of disease
	• During moulting period	• Examine pond for presence of shrimp shells. Adjust the feed according to consumption (reduce to approximately 50 percent) until shrimp return to normal appetite
	• Other animals present in the pond	• Apply tea deed cake if there are too many fish
	• Poor water quality	• Check water quality and improve aeration
All the feed i n the net gone but no faeces	• Feed not put in the net • Net dropped into the pond too quickly	• Check on workers
	• Net incorrectly placed, rope too short or net not flat	• Check nets
Increasing numbers of shrimp in the net	• Deteriorating pond bottom causes shrimp to move to edge of pond	• Check condition of pond bottom
		• Move nets to clean areas if necessary
		• Feed only in clean part of pond
	• Underfeeding	• Check survival and re-calculate the feed
Feed disappears from the net too quickly	• Deteriorating pond bottom causes shrimp to move to edge of pond	• Check condition of pond bottom, move nets to clean areas if necessary • Feed only in clean part of pond
	• Underfeeding	• Check survival and re-calculate the feed
	• Tray incorrectly placed	• Check nets
	• Fish in pond	• Look for fish in cast nets or large faeces in check trays • Kill the fish with tea seed cake

Source: Modified from Chanratchakool *et al.* (1998).

ANNEX 2
Feeding scheme for shrimp farming

Age (days)	Mean body weight (g)	Daily feeding rate (% of mean body weight)	Check tray (%)	Time of feed tray checking (hours)
1–20	PL15–1.0	20.0–5.0		
20–35	1.0–4.0	5.0–4.0		
35–50	4–6	6.0–5.0		
50–55	6–7	5.0–4.5	2.0	2.0
55–60	7–8	4.8–4.2	2.0	2.0
60–65	8–9	4.2–4.0	2.1	2.0
65–70	9–11	4.0–3.8	2.2	2.0
70–80	11–14	3.8–3.6	2.3	1.45
80–90	14–17	3.6–3.3	2.4	1.45
90–100	17–21	3.3–3.0	2.5	1.45
100–110	21–25	3.0–2.5	2.7	1.30
110–120	25–30	2.5–2.1	3.0	1.30
120–130	30–36	2.1–1.6	3.5	1.30
130–140	36–43	1.6–1.5	4.0	1.20
140–150	43–50	1.5–1.4	4.5	1.15

Source: NaCSA/MPEDA (2013).

On-farm feeding and feed management in whiteleg shrimp *(Litopenaeus vannamei)* farming in Viet Nam

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ABSTRACT

The study surveyed 97 whiteleg shrimp (WLS) farmers in Central and Southern Viet Nam in 2009. Farmers stocked at very high densities (100–200 shrimp per ha) and harvested in 80 to 100 days. Culture periods of less than 80 days were reported when shrimp were reared only to small sizes (12–15 g). Farmers used manufactured feed and rarely applied supplemental feeds. The feeds contain high protein levels, ranging from 36 to 44 percent. Dietary protein levels varied according to shrimp size. The feed conversion ratio varied from 1.1:1 to 1.2:1 and the shrimp yields were in the range of 10 to 20 tonnes/ha/crop. Shrimp farmers in Central Viet Nam had smaller ponds and often stocked at higher densities than the farmers in the Mekong delta (Southern Viet Nam). As a result, the shrimp yields in Central Viet Nam were often higher.

The production cost and benefits of WLS farming were analysed. The analysis showed that feed costs comprised 66 to 68 percent of total production costs. Costs for seed and fuel (electricity) were the second and third highest production costs, varying from 8 to 10 percent. Labour costs contributed only 2 percent of total production costs. The total production cost/ha/crop was US$32 000 and US$16 500 in Central and Southern Viet Nam, respectively. The cost-benefit ratios were 0.69 and 0.75 in Central and Southern Viet Nam, respectively. The results demonstrated that whiteleg farming in Central Viet Nam is more intensive but less profitable than farming in Southern Viet Nam.

While there is potential to further develop WLS farming in Southern Viet Nam, development has peaked in Central Viet Nam. Shrimp farmers often report disease outbreaks, especially in Central Viet Nam.

1. INTRODUCTION

Historically, shrimp farming in Viet Nam has been based on extensive production systems. More recently, intensive farming systems that require different feed and feed management strategies have been introduced.

1.1 Overview of shrimp farming in Viet Nam

1.1.1 Extensive production systems

Extensive shrimp farming is a traditional farming practice that has developed in the Mekong delta and other coastal provinces in Central and Northern Viet Nam. Extensive culture systems require water to be exchanged under tidal influences with the inflow bringing natural seed and feed to the culture ponds. Harvesting is undertaken on a bi-monthly basis during low spring tide events, when the ponds can be completely drained. Supplemental feeding is not used in extensive culture systems, and the shrimp rely completely on natural feed. Until 10 to 15 years ago, natural seed abundance of banana prawn (*Penaeus merguiensis*) and Indian white prawn (*P. indicus*) was sufficiently high to supply the ponds with juveniles. However, in recent years, and due to a decline in naturally produced postlarvae (PL), farmers have had to stock black tiger shrimp (*Penaeus monodon*) PL to improve their yields. The practice of stocking PL in this manner is known as the 'improved extensive system'. These two systems occupy a large proportion of the shrimp culture area in Viet Nam, particularly in the Mekong delta (Hung and Huy, 2007). In 2004, extensive and improved extensive systems accounted for 68 percent and 27 percent of the shrimp farming surface area in the Mekong delta, respectively (Phuong, Minh and Tuan, 2004).

1.1.2 Semi-intensive and intensive production systems

In semi-intensive production systems culturing black tiger shrimp (*P. monodon*), the natural food is supplemented with trash fish, small shrimp, Jawla paste shrimp (*Acetes indicus*) and cheap shrimp pellets (approximately US$0.8/kg) Stocking density ranges from 5 to 10 shrimp/m^2. Aeration is not used. The farms may either be operated as rotational shrimp/rice farms, or integrated into the mangrove areas. In 2003, there were 20 500 ha of semi-intensive shrimp farms in the Mekong delta (MoFI, 2003).

In the intensive production systems, black tiger shrimp are stocked at 20 to 50 shrimp/m^2. Ponds are usually constructed in areas at the top of the tidal prism, and have a surface area of 2 000 to 3 000 m^2. The system requires a high level of maintenance and management with respect to feeding, water quality control, and aeration. Though most farmers use commercially formulated shrimp feeds in these systems, some still follow traditional methods of improving yields by using fertilizers to stimulate natural productivity and by adding trash fish. The total surface area under intensive culture in 2003 was 15 534 ha (MoFI, 2004). The main culture species in the Mekong delta is tiger shrimp. Formulated feeds are mostly used in intensive systems, though some farmers combine formulated and farm-made feeds during the final days of the production cycle. Farm-made feeds include cooked trash fish, small shrimp and molluscs. Nhan (2005) demonstrated that in Quang Ngai province of Central Viet Nam, 30 percent of farmers still use farm-made feeds when intensively culturing tiger

FIGURE 1
A feeding tray used to monitor feed consumption and to adjust the amount of feed provided

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shrimp. Farmers use feeding trays (2 to 4 trays per 4 000 to 5 000 m² pond) to monitor consumption and to adjust the ration (Figure 1).

Pellets are fed using by broadcasting them over the pond surface. Feeding is restricted to two to three times per day, using a boat or floating raft. All feed producers provide feeding tables to calculate feeding rates and minimize over- or under-feeding. Table 1 provides an example of a recommended feeding strategy. Daily feed is adjusted according to shrimp size, and the portion of feed remaining on the feeding tray from the previous feed. Farmers normally distribute 3–4 percent of the daily feed ration onto feeding trays (2.8, 3.0 and 3.3 percent for 5–10 g, 10–20 g and >20 g shrimp, respectively). The feeding trays are checked after two hours of feeding. If the unfed feed left in the feeding tray is higher than 10 percent, the farmers reduce the feed ration at the next feeding. The ration size is increased when the feeding tray has been emptied. When well-managed, the feed conversion ratios (FCR) attained using commercially formulated feeds range from 1.3:1 to 1.5:1. In poorly managed systems, FCR can be as high as 2.5:1. Under intensive culture conditions, yields of up to 7 tonnes/ha/crop can be attained (Hung and Huy, 2007).

TABLE 1
Example of a feeding schedule for intensive culture using formulated feeds for black tiger shrimp

Stage	Shrimp size (g)	Feeding rate (kg/day)	Feed distributed in feeding tray (% of daily feed)	Feeding tray monitoring intervals (hours)
PL20-PL27	<0.2	1.0–1.5 kg/90 000 PL/day	NA	NA
PL28-PL35	0.2–0.6	1.5–2.0 kg/90 000 PL/day	NA	NA
PL36-PL45	0.6–1.5	6.0–6.5	2	3
PL46-PL55	1.5–5.0	5.5	2.4	2.5
PL56-PL75	5.0–10.0	4.5	2.8	2.5
PL76-PL95	10.0–20.0	3.8	3.0	2
>PL95	>20 g	3.5	3.3	2

Notes: PL = Postlarvae; NA = not applicable.
Source: Hung and Huy (2007).

Intensive shrimp farming based on whiteleg shrimp (*Litopenaeus vannamei*), hereinafter referred to as WLS, has been introduced to Viet Nam over the past ten years. WLS are native to the Western Pacific Coast of Latin America, and were introduced into Tahiti in the early 1970s to establish their potential for aquaculture. The successful production of this shrimp species in South America led to its introduction into Asia. The timing of these introductions (some illegal) was: Mainland China, 1988; Taiwan Province of China, 1995; Philippines, 1997; Thailand, 1998; Viet Nam, 2000; Indonesia, 2001; Malaysia, 2001; India, 2001 (Briggs *et al.*, 2004).

During 2002 to 2009, Thailand, Indonesia and China changed from tiger shrimp farming to WLA farming; WLS production now dominates the shrimp farming industries in these countries. In 2003 the Ministry of Fisheries, Viet Nam (MoFI) banned the production of WLS in the country for fear of the transmission of viral diseases between the introduced WLS and indigenous species such as tiger shrimp, and the potential impact that the introduction could have on biodiversity. Until 2006, and under pressure from producers, the Ministry restricted the production of WLS in Central and Northern Viet Nam, and prohibited its production in the Mekong delta (Southern Viet Nam). Since 2008, the Ministry has allowed the farming of WLS in the

Mekong delta. As a result of these restrictions, while WLS farming has been practiced in Viet Nam since 2000, its production remains small in comparison with that of the tiger shrimp. In 2009, 84 320 tonnes of WLS and 236 492 tonnes of tiger shrimp were produced (Table 2).

TABLE 2
Shrimp production and the area under cultivation in Viet Nam (2009)

Area/production	Tiger shrimp	WLS	Other shrimp	Total production
Surface area (ha)	598 679	18 628	12 136	629 443
Production (tonnes)	236 492	84 320	66 729	387 541

Source: MAR (2009).

During the initial period in which WLS was introduced to Viet Nam, PL were illegally imported from China. During this period, tiger shrimp production was severely impacted by white spot disease, especially in Northern and Central Viet Nam where farmers lost multiple crops, and in many cases had to abandon their ponds. In response, WLS farming was embraced by farmers as an alternative culture species – this despite the species being banned until 2006 for fear of the introduction of the Taura viral disease, and the potential impact on biodiversity.

Artificial breeding protocols are available for the production of both tiger shrimp and WLS (Khang, 2008). Over the past ten years, the number of shrimp hatcheries has increased rapidly from 2 086 units in 1998, producing approximately 6.6 million PL15 shrimp to 5 094 units in 2004, producing approximately 26 billion PL15 (MoFI, 2005). These hatcheries, supply seed to the entire country, and are primarily located in Central Viet Nam, but can now also be found in the Mekong delta (Khang, 2008). As there are no significant differences in breeding techniques between the two shrimp species, the hatcheries can produce either tiger shrimp or WLS. As WLS are not indigenous, the broodstock used in Viet Nam is imported. While large-scale hatcheries import SPF (Specific Pathogen Free) broodstock from Hawaii or Thailand, their smaller counterparts often import uncontrolled broodstock from China. Eyestalk ablation techniques are used to induce female maturation. The feeding strategies developed for WLS larvae are similar to those applied to tiger shrimp, with feeding strategies being dependent on developmental stage. At the zoeal stage, larval feeds mainly comprise live algae or algal powders (*Spirulina*) and microencapsulated feeds (e.g. Frippak, Lansy, V8-Zoae, V8-larval 1, 2, 3, 4). At the mysis stage, larvae are fed microencapsulated feed and live, newly hatched *Artemia* nauplii. At the postlarval stage, shrimp are fed both formulated feeds and live hatched *Artemia* nauplii (ECAA, 2009).

In 2004, the Ministry of Fisheries published quality standards for tiger shrimp feeds to regulate and control the quality of feed production. The standards obligate feed mills to comply with certain minimum standards: crude protein content should be 35 percent for grow-out shrimp (>20 g); and up to 42 percent for starter feeds (0.01 to 0.20 g). Gross energy should be at least 3 000 cal/kg for grow-out and 3 400 cal/kg for starter feeds. Other nutrients in formulated feed such as crude lipid, calcium, phosphorus, fibre, minerals, lysine and methionine and the allowable levels of aflatoxin are also standardized. There are about five to six types of feed that are produced for the different developmental stages of tiger shrimp. The nutrient composition of the various products does not differ much among producers. Table 3 provides an example of the general nutrient composition of tiger shrimp feeds. Feed is distributed through an elaborate network of dealers and sub-dealers throughout the country. Each company sets up its own distribution channels to cover markets in coastal provinces throughout Viet Nam (Hung and Huy, 2007).

TABLE 3
Examples of nutrient composition of commercial tiger shrimp feeds (percentage dry matter)

Feed type	Moisture (%)	Crude protein (%)	Crude lipid (%)	Crude fibre (%)	Ash (%)	Calcium (%)	Phosphorus (%)
Postlarvae	<11	>43	>5	<3	<16	>2.5	>1.5
Starter	<11	>41	>6	<3	<16	>2.5	>1.5
Grower	<11	>38	>6	<3	<16	>2.5	>1.5
Finisher	<11	>36	>6	<3	<16	>2.5	>1.5

Source: Hung and Huy (2007).

Government agents, working for the National Fisheries Quality Assurance and Veterinary Directorate (NAFIQUAVED) in central government, monitor the feed mills for compliance with the quality standards. In the past, shrimp farmers in Viet Nam experienced serious disease outbreaks, which at the time were attributed to environmental factors (Nhuong, 2006). Notably, the increased volumes of shrimp feed, therapeutants and other products that are associated with higher-intensity shrimp farming, creates serious problems. These occur when redundant shrimp feed and wastes that have not been treated are disposed of directly into the environment, polluting rivers and coastal areas, and impacting biodiversity. In addition, the risk of disease contamination continues to threaten the economic efficiency of the production systems (Khang, 2008). In 2001 and 2002, shrimp diseases caused significant damage to farmers in Central Viet Nam, and for this reason, many farmers switched from culturing tiger shrimp to WLS.

According to government regulations (Good Aquaculture Practices approved by the Government of Viet Nam), prior to discharging effluent shrimp farms should treat their pond water to eliminate diseases and reduce emissions. Only large-scale farms can afford to apply these regulations – small-scale farms, generally comprising 1 to 2 ponds, have insufficient land to the construct the necessary water-treatment ponds needed. In the past, attempts have been made to close these small-scale farms. However, as the government has a policy to alleviate rural poverty, a dilemma arose as to whether to apply the effluent control regulations, or promote small scale farming as a mechanism with which to reduce rural poverty. As a result, some farms currently do not treat their effluent waters.

At present, WLS farming has expanded to the whole country (North, Central and Southern Viet Nam). The WLS farming production system is intensive, using high stocking densities - extensive production techniques are not applied to WLS farming. In comparison with tiger shrimp farming, WLS production dominates in Central and Northern Viet Nam (Table 4).

TABLE 4
Production of tiger and whiteleg shrimps in three areas of Viet Nam in 2009 (tonnes)

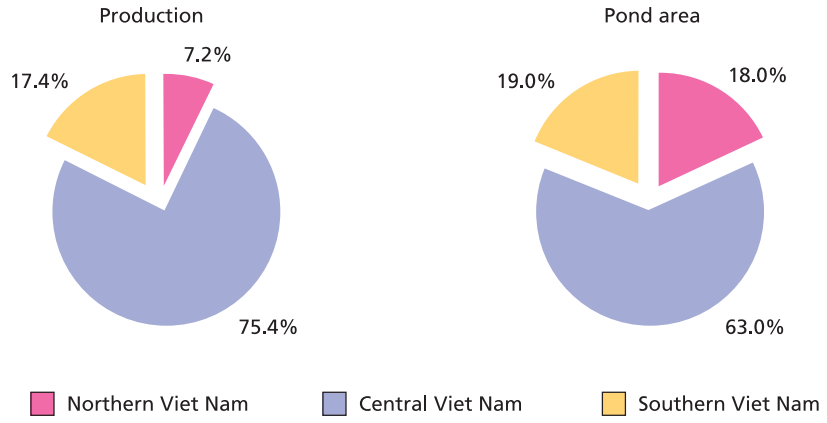
Locations	WLS	Tiger shrimp	Total
Northern Viet Nam	6 058	3 427	9 485
Central Viet Nam	63 554	9 321	72 875
Southern Viet Nam	14 708	223 745	238 453
Total	84 320	236 493	320 813

Source: MAR (2009).

In Southern Viet Nam tiger shrimp is the dominant culture species, accounting for 74.9 percent of the total shrimp production in the region; while WLS farming started only a couple of years ago, production has rapidly increased and now stands at 4.93 percent of the total shrimp production.

Central Viet Nam is the leading area for WLS farming, accounting for 75.4 percent of the country's total production, and 63.0 percent of the production area (Figure 2). Southern Viet Nam accounts for 17.4 percent of production, occupying 19 percent of the production area. In contrast Northern Viet Nam accounts of 7.2 percent of the country's production, occupying 18 percent of the surface area available for production.

FIGURE 2
Production and surface areas associated with whiteleg shrimp farming in Viet Nam in 2009



Source: MAR (2009).

As discussed, WLS farming represents a relatively novel farming practice in Viet Nam, and there is currently a paucity of published information pertaining to the feed and feed management practices that are in use in the country. The present study was undertaken to obtain a better understanding of these details, and to evaluate the production costs and production efficiencies.

The objectives of the study were to:

- Provide a review of the current status of WLS farming in Viet Nam.
- Provide a synthesis of current feed use and feeding practices, including the choice of feed, availability, feed transportation and on-farm storage systems.
- Study the existing feeding strategies used in WLS farming, with specific focus on feeding frequency, feeding rate and methods.

2. METHODOLOGY

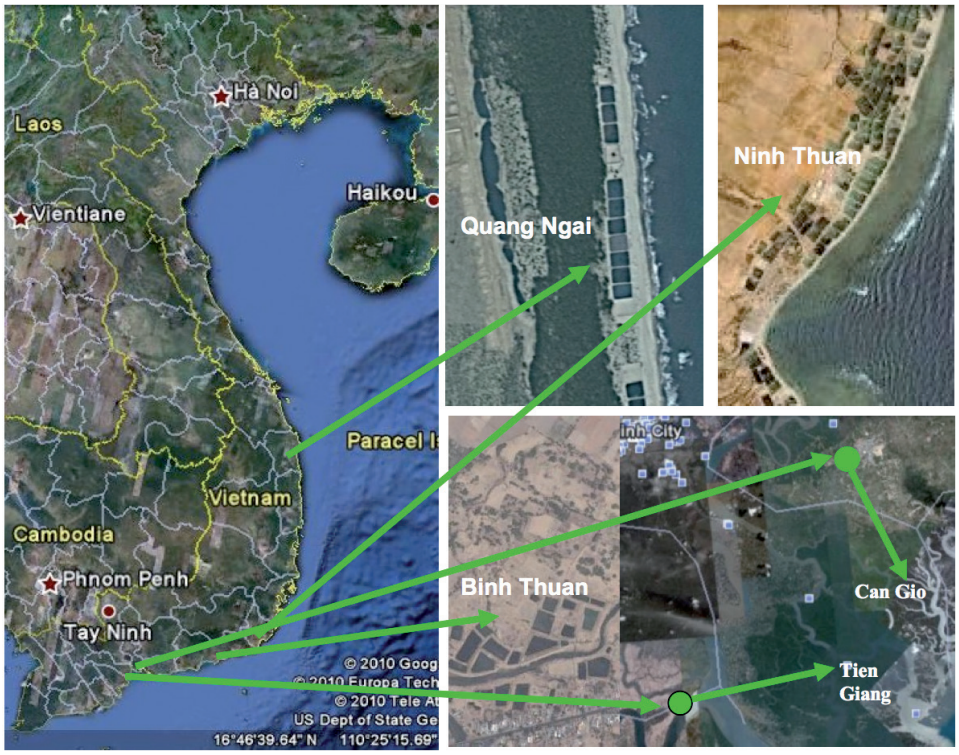
The study was conducted between January and mid-February 2010.

2.1 Site selection for the survey

While WLS is cultivated from N orth to Southern Viet Nam, the survey was restricted to Central and Southern Viet Nam (Figure 3), which is the major area where WLS farming occurs.

A total of 97 shrimp farmers were interviewed during the survey period. In Central Viet Nam 57 shrimp farmers were interviewed in Binh Thuan, Ninh Thuan and Quang Ngai provinces. In Southern Viet Nam 40 shrimp farmers were interviewed in Ho Chi Minh and Tien Giang provinces. All farmers were interviewed using structured questionnaires. Sample numbers for each province were determined according to the regional distribution of the farms, and to ensure a representative sample of all farming practices (Table 5). The farmers that were selected to participate in the survey were selected at random.

FIGURE 3
Map of five different studied locations along the coast of Viet Nam



Source: http://maps.google.com/maps (accessed 15 August 2010).

TABLE 5
Survey questionnaire – regional distribution

Locations		Sample size	Total
Central Viet Nam	Quang Ngai Ninh Thuan Binh thuan	5 27 25	57
Southern Viet Nam	Can Gio-HCM city Tien Giang	20 20	40

Source: Field survey (2010).

A total of 43 farmers agreed to participate in an economic analysis of their farming activities. Those that failed to participate in this section of the survey did so because they either lacked the necessary information, or viewed their information as proprietary knowledge. Survey data was coded and entered into an MS Excel spreadsheet for analysis.

2.2 Questionnaire limitations

The survey was only carried out on 97 shrimp farmers in Central and Southern Viet Nam and did not include farmers in Northern Viet Nam – this omission was due to time limitations and restricted human resources to undertake the survey. In addition, the study did not interrogate farmers about hatchery feeds and larval feeding.

3. RESULTS AND DISCUSSION

3.1 Experience of shrimp farming

The survey revealed that tiger shrimp farmers in Central and Southern Viet Nam had more experience than WLS farmers. More than 50 percent of the total number of WLS farmers interviewed had less than two years of experience, and very few farmers (4.8 percent) had more than four years of experience (Table 6). Farmers in Southern Viet Nam had fewer years of experience than farmers in Central Viet Nam.

TABLE 6
Experience profile of the shrimp farmers in Central and Southern Viet Nam

Experience (years)	Central Viet Nam		Southern Viet Nam	
	WLS (%)	Tiger shrimp (%)	WLS (%)	Tiger shrimp (%)
0–2	47.37	-	65.00	-
2–4	43.86	59.65	32.50	52.50
4–8	8.77	22.81	2.50	40.00
>8	-	17.54	-	7.50

Source: Field survey (2010).

3.2 Farm size and shrimp ponds

In general, prawn farms are relatively small (Table 7). Across the two survey regions, 71 percent of the farms were less than 1 ha in size, 18.3 percent were between 1 and 2 ha, and only 10.7 percent were over 2 ha. Fewer large (>2 ha) farms were found in the South Viet Nam areas surveyed. With respect to the pond sizes that were in use, 66.7 percent of farms in Central Viet Nam used ponds that were less than 0.3 ha. In contrast, only 22.5 percent of the pond sizes in Southern Viet Nam were 0.3 ha, with the majority (70 percent) being 0.3–0.6 ha. Only an average of 4.6 percent of the farmers reported using ponds larger than 0.6 ha.

TABLE 7
Characterisation of farm and pond sizes used across Central and Southern Viet Nam

Farm/pond size	Central Viet Nam (%)	South Viet Nam (%)	Mean (%)
Farm size (ha)			
<1 ha	71.9	70.0	71.0
1–2 ha	14.1	22.5	18.3
>2 ha	14.0	7.5	10.7
Pond surface area (ha)			
<0.3 ha	66.7	22.5	44.6
0.3–0.6 ha	31.5	70.0	50.8
>0.6 ha	1.8	7.5	4.6

Note: data presented as regional percentages and the mean for both regions.
Source: Field survey (2010).

3.3 Feed and feeding management

As WLS farming is practiced under intensive culture conditions, farmers use compound aquafeeds and do not use supplemental feeds such as trash fish, small shrimp, or other low-grade feedstuffs. Prior to 2006, compound aquafeeds specifically formulated for

WLS were unavailable in the country. In their absence, farmers used formulated feeds that were designed for tiger shrimp. In 2006, the government formally allowed farmers to culture WLS, and thus the commercial feed companies started to produce feeds that were specifically formulated for use with this species. In September 2009, the government issued a feed standard for WLS in which the gross nutrient composition, feed size and form (crumble, pellet) was specified (Table 8).

Currently, there are more than ten feed mills producing compound aquafeeds for WLS in Viet Nam. The feed producers are required to follow the manufacturing standards for the various feed types (Table 8). To ensure compliance with the standards, Government agencies randomly inspect feed quality by testing samples of the feeds that are being distributed in the market. Most of the feed mills are run by foreign companies: these have invested in Viet Nam primarily to produce feed for the local market, but may also export small amounts to neighbouring countries. The arrival of multi-national aquafeed companies such as the CP group, Uni-President, and Grobest Company, have overwhelmed the local shrimp feed producers; often local feed manufacturers are no longer able to compete with multinational aquafeed producers. These companies manufacture between 6 and 8 feed types (Annexes 1 and 2). The feeds produced are classified as starter, grower and finisher feeds (Table 9). The starter feeds typically have dietary protein levels of 40–42 percent protein, with the finisher feed having lower protein contents at around 36–38 percent. The feed price varies according to its protein levels.

TABLE 8

Quality norms and feed standards for whiteleg shrimp

Stage	Feed form	Feed size	Digestible protein not less than (%)	Crude lipid not less than (%)	Fibre not higher than (%)	Moisture (%)	Lysine (% feed)	Methionine (% feed)	Ca:P ratio
Zoea to mysis	Powder	250 µm	40	6–8	3	10	2.0	0.9	1.0–1.5
PL1 to PL15	Powder/ Crumble	250 µm–0.5 mm	40	6–8	3	10	1.9	0.8	
Juvenile (1.2–2.5 cm)	Crumble	0.4–0.8 mm	38	5–7	3	11	1.8	0.8	
Juvenile 2 (2.5–3.5 cm)	Crumble	0.7–1.68 mm	38	5–7	4	11	1.8	0.8	
Shrimp 1 (1–3 g)	Crumble/ pellet	1.4–2.2 mm	38	5–7	4	11	1.7	0.7	
Shrimp 2 (3–12 g)	Pellet	1.5–2.3 mm	36	4–6	4	11	1.6	0.7	
Shrimp 3 (12–25 g)	Pellet	1.8–2.4 mm	34	4–6	4	11	1.5	0.7	
Shrimp 4 (> 25 g)	Pellet	2.2–2.6 mm	32	4–6	4	11	1.5	0.7	

Source: MAR (2009).

TABLE 9

Summary of commercial feed used for whiteleg shrimp in Viet Nam

	Starter	Grower	Finisher
Protein content (%)	40–42	38–40	36–38
Feed form	Crumble/powder	Pellet	Pellet
Feed size (cm)	Ø 1; L:2–4	Ø 1.4; L:2–4	Ø 2.0; L:3–5
Shrimp stage	PL to 1.0 g	1.0–10 g	10–15 g
Price (US$/kg)	1.07–1.08	1.05–1.07	1.03–1.05

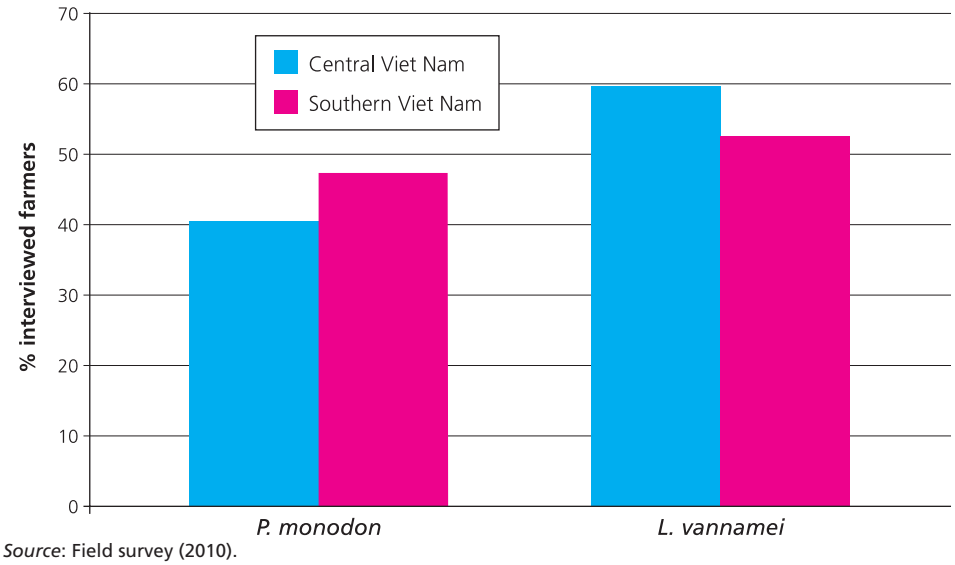
Notes: Ø: diameter; L: feed length.

Source: Synthesis from data of various feed mills.

The survey found that farmers stocking WLS used formulations containing protein levels between 36 to 42 percent (Table 9). These dietary protein levels should be considered greater than the optimal for the species. Hertrampf and Piedad-Pascual (2000) reported that WLS have a dietary protein requirement in the range of 32 to 35 percent protein. Hu *et al.* (2008) undertook a study to determine the effect of the growth and body composition of WLS juveniles fed different ratios of dietary protein to energy. These authors demonstrated that a diet containing 34 percent protein and 7.5 percent lipid with a protein:energy ratio of 21.1 mg protein/kJ was optimum for the WLS, and that increases in dietary lipid levels did not elicit a significant protein sparing effect.

This contrasts to the dietary protein requirement for tiger shrimp, which is reportedly in the range of 36 to 42 percent (Shiau, 1998). These findings suggest that some WLS farmers are using feeds that are designed for use with tiger shrimp. Indeed, approximately 40 to 50 percent of the farmers interviewed in the study reported using tiger shrimp feeds when culturing WLS (Figure 4). As WLS feeds with the correct protein levels are readily available on the market, this finding suggests that despite their unsuitability, farmers have become used to using tiger shrimp feeds for WLS culture, and select these feeds in preference to the WLS feeds.

FIGURE 4
The percentage of whiteleg shrimp farmers that reported using feed designed for either tiger or whiteleg shrimp



Source: Field survey (2010).

Despite using feeds that have already been formulated to contain sufficient vitamins and minerals, farmers often 'top dress' their feeds with additional vitamins and minerals. The practice of 'top dressing' is believed by many farmers to prevent diseases, promote growth and enhance digestibility. In this regard, Vitamin C is often applied as a health prophylactic at a dose of 2–3 g/kg feed (Table 10). Moreover, Moss, Forster and Tacon, (2006) studied WLS growth using different water sources (groundwater, pond water) with and without vitamin supplements and found that the increased natural productivity in pond production systems provided sufficient vitamins to the shrimp, and thus the quantity of vitamins in the formulation could be reduced. It seems that algae and microbes probably contributed significantly to this effect. By exploiting endogenously produced microbes and associated detritus, shrimp farmers and feed manufacturers can substantially reduce vitamin levels in shrimp feeds (Moss, Forster and Tacon, 2006). In addition, farmers regularly supplement their feeds with digestive enzymes (e.g. proteases, amylases, cellulases and lipases) in an attempt to enhance feed digestibility (Table 10).

TABLE 10
Summary of feed supplementation in whiteleg shrimp feed in Viet Nam

Supplemented Nutrients	Composition	First month	Second month	Third Month
Vitamin C	Ascorbic acid 10%	3–5 g/kg feed 1–2 times/day	2–3 kg/feed 1 time/day	2–3 kg/feed 1 time/day
Nutrients/additives	Sorbitol, lysine, methionine, vitamin B	3–5 ml/kg feed 1–2 times/day	2–3 ml/kg feed 1 time/day	NA
Premixes	Minerals and vitamins	2–3 g/kg feed 1–2 times/day	2–3 g/kg feed 1–2 times/day	2–3 g/kg feed 1–2 times/day
Enzyme mixtures	Proteases, amylases, cellulases, lipases	2–3 g/kg feed 1–2 times/day	2–3 g/kg feed 1–2 times/day	2–3 g/kg feed 1–2 times/day

Source: Field survey (2010).

3.4 Disease management

If a disease should occur within 60 days of stocking, farmers often use chlorine to eradicate the disease and kill the shrimp. This is a preventative measure that is designed to restrict the spread of the disease. If the disease outbreak occurs on the farm after 60 days from stocking, farmers undertake an emergency harvest. In an attempt to resolve disease issues, some farmers reported supplementing their feeds with antibiotics (Norfloxacine or Cyproxacin). The success rate of this strategy was reported to be very low.

3.5 Pond fertilization protocols

The practice of using fertilisers in the preparation of the culture ponds and to stimulate natural productivity is not commonly applied to WLS culture. Only 17.5 percent of farmers reported using fertilizers to prepare ponds, and only 3 percent reported applying fertilizers during the grow-out period. There was no appreciable difference in the use of fertilizers between the farmers in Central and South Viet Nam (Table 11).

TABLE 11
The use of fertilizers during pond preparation and during the grow-out phase

	Central Viet Nam (% use)	Southern Viet Nam (% use)	Average (% use)
Pond preparation			
No fertilizer use	82.46	82.50	82.48
Fertilizer use	17.54	17.50	17.52
Grow-out			
No fertilizer use	96.49	97.50	97.00
Fertilizer use	3.51	2.50	3.00

Source: Field survey (2010).

Of those farmers that do apply fertilizers during the pond preparation phase of production, poultry litter (organic fertilizer) and urea or NPK (Nitrogen, Phosphorus and Potassium) are applied (Table 12). Fertilizers are not applied during the grow-out phase; however, chemicals are applied at different dosages during both production phases (Table 12). The combination of high protein feeds and the intensification of the production systems cause large amounts of nutrients to be released into the water during the grow-out phase. The accumulation of these nutrients can cause the shrimp pond waters to become eutrophic. In order to limit nutrient concentrations in the production ponds during grow-out, pond fertilization is not undertaken. In contrast, farmers use large amounts of lime during both pond preparation and grow-out. The farmers in Southern Viet Nam use lime at a higher dosage than the farmers in Central

Viet Nam. This is due to soil acidity in Southern Viet Nam, and the need to increase the pH of the production ponds. Dolomite is often applied during grow-out and pond preparation, with Zeolite being used to reduce ammonia levels in the grow-out stage.

TABLE 12
Fertilizers and chemical usage in whiteleg shrimp farming in Central and Southern Viet Nam

Duration	Fertilization		Chemicals		
	Poultry litter (kg/1 000 m²)	Urea, NPK (kg/1 000 m²)	Lime (kg/1 000 m²)	Zeolite (kg/1 000 m²)	Dolomite (kg/1 000 m²)
Central Viet Nam					
Pond preparation	13–36	2–4	20–150	-	6–40
Grow-out	-	-	300–400	20–50	150–200
Southern Viet Nam					
Pond preparation	10–20	5–15	150–200	-	6–40
Grow-out	-	-	500–600	20–30	100–150

Source: Field survey (2010).

3.6 Stocking densities and feeding practices

In comparison with tiger shrimp farming, the stocking densities applied to WLS farming are usually higher. Seventy five percent of farmers in Central Viet Nam stocked at densities between 100 to 200 PL/m², with 12 percent stocking at rates above 200 PL/m². In contrast, farmers in Southern Viet Nam usually stocked at lower densities, with 80 percent of farmers reporting stocking rates of less than 100 PL/m² and none stocking at densities higher than 200 PL/m² (Table 13). The lower stocking rates recorded in Southern Viet Nam are probably attributable to the soil structure and muddy pond bottoms associated with this region, which reduce the suitability for higher density culture.

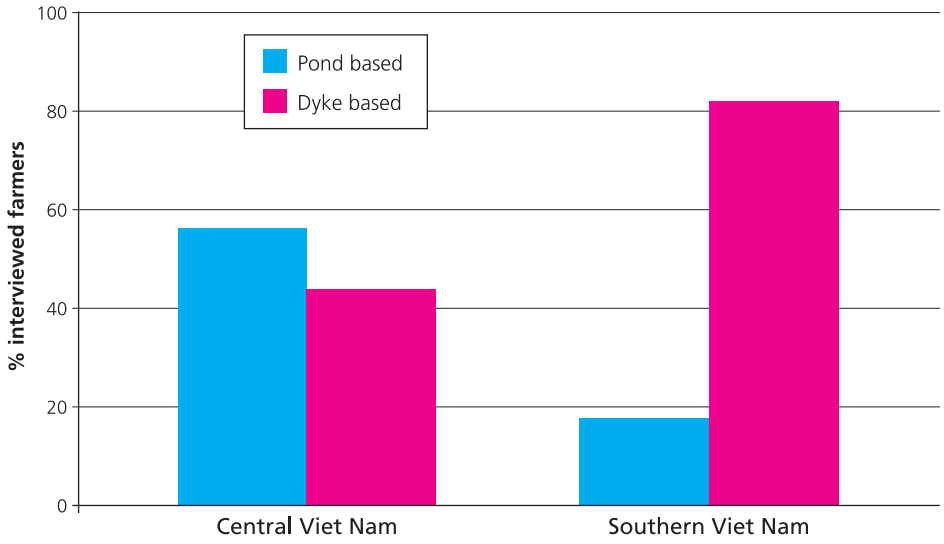
The practice of stocking at higher densities in Central Viet Nam was associated with a longer production cycle. Indeed, 60 percent of farmers in Central Viet Nam reported a grow-out period in excess of 80 days. In contrast, 62.5 percent of farmers in Southern Viet Nam reported grow-out periods of less than 80 days, and no farmers reported grow-out periods in excess of 100 days (Table 13). With respect to the size of the shrimp at harvest, there were few appreciable regional differences between the harvest sizes. The exceptions were that in Central Viet Nam, 21 percent and 43.9 percent of the crop was below 10 g and between 10-12 g respectively, while in the South, these figures were 7.5 percent and 60 percent respectively.

TABLE 13
Regional differences between stocking densities, culture duration and sizes at harvest

Stocking density (shrimp per m²)	Central Viet Nam (%)	Southern Viet Nam (%)
<100	12.3	80.0
100–200	75.4	20.0
>200	12.3	0.0
Culture duration		
<80 days	40.3	62.5
80–100 days	50.9	37.5
>100 days	8.8	0.0
Shrimp size (g)		
>12 g	35.1	32.5
10–12 g	43.9	60.0
<10 g	21.0	7.5

Source: Field survey (2010).

FIGURE 5
Feed management – feed distribution patterns (feed *in situ* in ponds vs. feeding from dykes)



Source: Field survey (2010).

Farm feeding practices are presented in Figure 5. Broadcast feeding is either undertaken from a boat or raft or *in situ* in the pond (Figure 6). To ensure a uniform distribution of the feed, wires are placed parallel to the pond dykes and feeding is undertaken along these lines (Figures 7 and 8). Alternatively, feeding is undertaken from the pond dykes. In Central Viet Nam, 56 percent of farmers employ pond based feeding practices as compared to just 18 percent in Southern Viet Nam where the majority of farmers distributed feed from the dikes. The reasons for this were the small surface area of the shrimp ponds as well as the higher stocking densities.

Feeding frequency is presented in Table 14. The majority of farmers (±60 percent) feed four times a day for the first 30 days post stocking. After thirty days post stocking, the majority of the farmers (89.5 percent) in Central Viet Nam reduced their

FIGURE 6
Feeding in situ

COURTESY OF FAO/L.T. HUNG.

FIGURE 7
A shrimp pond with feeding lines to ensure uniform distribution of the feed

COURTESY OF FAO/L.T. HUNG.

FIGURE 8
Distribution of feed along a feed line using a boat

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feeding schedules to three times per day. In contrast in the South, the majority of farmers (72.5 percent) maintained feeding at 4 times a day during this period. The pellet size, feeding frequency and feeding rate data is summarised in Table 15 and provides an indication of the pellet sizes used, feeding frequency and feeding rates that are applied.

TABLE 14
Feed management: feeding schedules

Feeding schedules (feeds/day)	Central Viet Nam (% of farmers)		Southern Viet Nam (% of farmers)	
	30 days	After 30 days	Before 30 days	After 30 days
2	5.2	-	-	-
3	31.6	89.5	40.0	27.5
4	63.2	8.8	60.0	72.5
5	-	1.7	-	-

Source: Field survey (2010).

TABLE 15
Feed management – pellet size, feeding frequency and feeding rates.

Duration (months)	Shrimp size (g)	Feed type (cm)	Feeding (frequency/day)	Feeding rate (% body weight)
1	1–4	Ø 1.2 L: 2–4	4	7–8
2	5–8	Ø 1.4 L: 2–4	3–4	5–6
3	9–102	Ø 1.7 L: 2–4	3	3–4

Ø = feed diameter; L: feed length.
Source: Data summarized from survey.

On the establishment of a new cluster of shrimp farms, a feed shop would normally be built in the vicinity to supply the farmers with feeds, chemicals, fertilizers and any other supplies that may be required. The survey showed that most farms (88–98 percent) in both Central and Southern Viet Nam usually bought feed within a radius of 10 km of their farms (Table 16). The distance from the farm to the feed shop

and the topography of the region has an influence on the type of transport that is used to collect the feed. In Southern Viet Nam, farmers often used motorbikes to carry their feed while farmers in Central Viet Nam used several alternative forms of transport. Coaches (suitable for use on sand e.g. beach access) were only used in Central Viet Nam.

TABLE 16
Feed availability and transportation in Central and Southern Viet Nam

Distance between farm and feed shop (km)	Central Viet Nam (%)	Southern Viet Nam (%)
≤10 km	87.7	97.5
10 – ≤20 km	3.5	0.0
>20 km	8.8	2.5
Vehicle		
Lorry	40.4	25.0
Motorbike	36.8	75.0
Coach	22.8	0.0
Feed storage		
Storehouse	17.5	47.5
House	82.5	52.5

Source: Field survey (2010).

The storage of feed is an important issue since feed quality rapidly deteriorates if not stored in an appropriate manner. Depending upon their living conditions, farmers usually store feed in a storehouse or at their own houses (Figure 9). In Central Viet Nam, where the majority of shrimp ponds have been built along the beach, 83 percent of the farmers have built temporary houses in which to live and store their feed. In contrast, in Southern Viet Nam approximately half the farmers use a dedicated storehouse with the remainder storing feed at their homes (Table 16).

FIGURE 9
A typical feed store in central Viet Nam

COURTESY OF FAO/L.T. HUNG.

3.7 Efficiency of feed use and shrimp yields

The majority of farmers (79.9 percent) attain feed conversion ratios (FCR) between 1.0:1 and 1.2:1 (Table 17).

TABLE 17
Regional differences between feed conversion ratios and shrimp yields

Feed conversion ratio (FCR)	Central Viet Nam (% of farmers)	Southern Viet Nam (% of farmers)	Average (% of farmers)
1.0:1 – 1.1:1	38.6	45.0	41.8
1.1:1 – 1.2:1	38.6	37.5	38.1
higher than 1.2:1	22.8	17.5	20.1
Shrimp yield (tonnes/ha/crop)			
<10	15.8	97.5	56.7
10–20	56.1	2.5	29.3
>20	28.1	0.0	14.0

Source: Field survey (2010).

Farming yields in Central Viet Nam were higher than those recorded from Southern Viet Nam. The majority of farmers (84.2 percent) in Central Viet Nam recorded yields of 10 to 20 tonnes/ha/crop or more. In contrast, the majority of the farmers (97.5 percent) in the South reported yields of less than 10 tonnes/ha/crop. Clearly, the high stocking densities reported in Central Viet Nam (Table 13) accounted for these high yields. In addition, farmers in Central Viet Nam often locate their shrimp ponds along the beach, which facilitates water exchange rates of 5 to 10 percent of pond volume per day. In contrast, farmers in Southern Viet Nam often site their ponds far from the coast to minimize water exchange in order to reduce viral disease transmission through the water supply. As a result of higher water exchange rates in Central Viet Nam, higher stocking densities are feasible and higher yields are attained.

A comparison between the WLS farming practices in Thailand (Wyban, 2007) and Viet Nam (Table 18) suggests that while the stocking densities used in Central Viet Nam are similar to those that are used in Thailand (100–200 PL/m^2), the grow-out period in Viet Nam is shorter. As a result, the harvest size of shrimp from Central Viet Nam is smaller than in Thailand. Furthermore, farming practices in Central Viet Nam and Thailand are more intensive, produce greater yields and require longer grow-out periods than those applied to Southern Viet Nam.

TABLE 18
Comparative production parameters of WLS farming in Thailand and Viet Nam

Production parameters	Thailand[a]	Central Viet Nam	Southern Viet Nam
Density (PL/m^2)	120–200	100–200	<100
Crop duration (days)	105–120	80–100	<80
Harvest size (g)	21–25	10–12	12
Yield (tonnes/ha/crop)	24	10–20	<10

Sources: [a]Wyban (2007); Field survey (2010).

3.8 Cost-benefit analysis

Production costs in Central Viet Nam are US$32 007 per crop/ha, and are appreciably higher than those in Southern Viet Nam where they are US$16 460 per crop/ha (Table 19). The discrepancy in production costs is due to the higher stocking densities that are used in Central Viet Nam. Feed costs represent the single highest production

cost and account for 66–68 percent of total costs. Shrimp seed represented the second highest production cost accounting for 8.9–11.5 percent. The third highest production costs were for the fuel and electricity that were required for pond aeration and water exchange; these costs accounted for 8.4 percent of the production costs. Labour costs occupied a very small component of the production costs (~2 percent).

The total gross revenues and net returns per hectare per crop from farming in Central and Southern Viet Nam were US$54 000 and US$21 993, and US$28 737 and US$12 777 respectively. The benefit-cost ratios for WLS farming in Central and Southern Viet Nam were 0.69 and 0.75, respectively.

TABLE 19

Cost benefit analysis of WLS farming in Central and Southern Viet Nam

Production cost	Central Viet Nam		Southern Viet Nam	
	(US$/ha/crop)	(% total cost)	(US$/ha/crop)	(% total cost)
Variable costs				
Seed	2 832.26	8.85	1 890.58	11.49
Shrimp feed	21 921.96	68.49	10 893.74	66.18
Chemicals and drugs	1 961.77	6.13	1 095.54	6.66
Electricity and fuel	2 705.10	8.45	1 380.02	8.38
Harvesting cost	300.88	0.94	43.33	0.26
Pond preparation	448.27	1.40	261.60	1.59
Labour	623.46	1.95	336.26	2.04
Total variable costs	30 793.70	96.21	15 901.07	96.61
Fixed costs				**0.00**
Land use cost	342.06	1.07	15.04	0.09
Depreciation	871.62	2.72	543.48	3.30
Total fixed cost	1 213.68	3.79	558.52	3.39
Total production cost	32 007.38	100.00	16 459.59	100.00
Net yield (tonnes/ha)	17.1		9.1	
Production cost (US$/kg shrimp)	1.87		1.81	
Total gross revenues	54 000.00		28 736.84	
Net returns	21 992.62		12 277.24	
Benefit-cost ratio	**0.69**		**0.75**	

Source: Field survey (2010).

The production costs associated with WLS farming in Thailand are approximately double those of Central Viet Nam and triple those of Southern Viet Nam (Table 20). The higher stocking densities and longer culture periods that are applied in Thailand account for these differences. In addition, the gross revenues and net returns of farming in Thailand are very much higher than those attained in Viet Nam. However, the benefit-cost ratio of shrimp farming in Thailand is lower than in Viet Nam. Intensive farming usually results in a higher net returns per ha per crop while the benefit-cost ratio shows the opposite.

TABLE 20
Comparison of cost/benefit ratios and production costs in WLS farming in Viet Nam and Thailand

Parameters	Central Viet Nam	Southern Viet Nam	Thailand[1]
Total production cost (US$/ha/crop)	32 007	16 460	60 000
Total gross revenues (US$/ha/crop)	54 000	28 736	96 000
Net returns (US$/ha/crop)	21 992	12 277	36 000
Benefit-cost ratio	0.69	0.75	0.60

Source: Field survey (2010); [1]Wyban (2007).

4. CONCLUSION AND RECOMMENDATIONS

WLS farming represents a relatively new farming activity in Viet Nam. Over the past few years, there has been a rapid expansion of the sector, especially in the South, and in response to the removal of the Government ban on farming this species. While farmers have adopted new culture techniques that are appropriate to the species, some farmers still use culture techniques and feeds that were designed to be used for tiger shrimp culture. The survey revealed that the farmers in Central Viet Nam have more experience culturing the species than those in the South of the country, and that different culture technologies are used in both regions. This is primarily a response to regional differences in the bottom structure and topography of shrimp ponds. Shrimp ponds in the Central region are often small with sandy substrates while in the South ponds are usually larger with muddy substrates.

Farmers almost always use manufactured compound aquafeeds, and very few utilize supplemental feeds such as trash fish, small shrimp, or used fertilizers to enhance the natural productivity of the culture systems. The compound aquafeeds that were used had a protein content of 36–42 percent. The protein content of these feeds is higher than that required by the species; this was attributed to farmers using feeds that were designed for tiger shrimp. Feed conversion ratios (FCR) varied between 1.1:1 and 1.2:1.

Farmers stocked at densities up to 100 to 200 shrimp/m^2. Farmers in Central Viet Nam often stocked at a higher density than those in the south of the country. In the central region, the culture duration was longer, size at harvest smaller, and production cost per kg shrimp higher. Typically, farmers feed between 3 to 4 times per day during 30 days post-stocking, and reduce this to 3 times per day thereafter.

The production cost analysis indicated that feed costs accounted for between 66 to 68 percent of total production costs, and that production costs per unit varied between US$1.81 to 1.87/kg shrimp. At these production costs, farmers could be profitable if they attained farm gate prices of US$2.0 to 2.2/kg. However, WLS farmers use high protein feed pellets (which are designed for tiger shrimp), often in the belief that the high stocking densities used in WLS farming make their use desirable. In addition, the norm for WLS feed (Table 8) also indicated the protein levels in the finisher diets should be 32 to 34 percent crude protein; therefore, feed mills need to produce finisher feeds specifically for WLS with lower protein levels. Government extension agents need to be trained to assist farmers to recognise that reducing the use of diets with unnecessarily high protein levels would reduce feed costs and increase profitability.

Although WLS farming represents a relatively new farming practice in Viet Nam, diseases have already impacted production in some areas of the country, potentially negatively affecting the sustainability of the sector. In 2005, a study in Ben Tre province (Mekong delta) showed that a viral disease outbreak had spread to 1 190 ha of shrimp ponds and, by 2006, the area affected had increased to 1 259 ha (Kang, 2008). At present

there is considerable information pertaining to WLS viral disease outbreaks in the media (Vietnamnet, 2009).

Many farmers that previously suffered from the viral disease outbreaks that affected the tiger shrimp sub-sector have now started to farm WLS. While these farmers have benefited from the change in species, uncontrolled seed production and poor water resource management could potentially result in similar disease outbreaks in WLS farming. In order to mitigate this risk, the government should encourage the importation of SPF broodstock from Hawaii, and strictly control the illegal importation of uncontrolled broodstock from China – even though there is currently no ban on imported broodstock from China. In parallel, the government should provide support to farmers to apply Good Aquaculture Practices (GAP) to reduce the impact of disease transmission and to protect the environment.

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ANNEX 1

Feed composition and feeding schedule for whiteleg shrimp of the Uni-President Company

Feed code	N310	N311	N312	N312A	N313	N314	N315	N316
Crude protein (%)	42	40	40	40	40	37	37	36
Crude lipid (%)	4	4	4	4	4	5	5	5
Fibre (%)	3	3	3	3	3	4	4	4
Ash (%)	13	13	13	13	13	13	13	13
Moisture (%)	11	11	11	11	11	11	11	11
Growing stage	PL10–15	PL15–25	PL25–1g	PL25–1g	1–3g	3–7g	7–15g	>15 g
Feeding rate (% body weight)	25–30	20–25	15–20	15–20	10–15	5–10	3–5	<3
Feeding frequency (times/day)	4–6	4	4	4	4	4	4–5	4–5
Size of feed (cm)	40# Ø	18–40#	14–18#	Ø 1.2; L2–4	Ø 1.4; L2–4	Ø 1.7; L2–4	Ø 2.0; L3–5	Ø 2.0; L3–5

Notes: # = mesh size: 40 # = 0.42 mm; 18–40# = 0.42–1.0 mm; 14–18# = 1.0–1.41 mm Ø: diameter (cm); L = length.

ANNEX 2

Aquafeed feed type and retail price of feed from different companies in Viet Nam (2010)

Name of Manufacturer	Type of aquafeed							
Tongwei	**Product type**	**Y110**	**Y111**	**Y112**	**Y113**	**Y114**	**Y115**	
	Protein (%)	40	40	38	38	36	36	
	Price US$/kg	1.08	1.07	1.06	1.06	1.05	1.05	
Grobest	Product type	1	2	2M	2ML	2L	3	4
	Protein (%)	40	40	40	39	39	39	39
	Price US$/kg	1.06	1.05	1.05	1.04	1.04	1.03	1.02
Tomboy	Product type	No 1	No 2	No 2L	No 2P	No 3	No 4	No 5	No 6
	Protein (%)	40	40	40	40	38	38	37	36
	Price US$/kg	1.10	1.09	1.09	1.09	1.08	1.07	1.06	1.06
Uni-President	Product type	N310	N311	N312	N312A	N313	N314	N315	N316
	Protein (%)	42	40	40	40	40	37	37	36
	Price US$/kg	1.07	1.06	1.05	1.05	1.04	1.04	1.03	1.03
CP	Product type	7700	7701	7702	7703	7703P	7704S	7704	
	Protein (%)	40	40	40	40	38	38	36	
	Price US$/kg	1.06	1.06	1.06	1.05	1.04	1.03	1.03	

SECTION C
INVITED REVIEWS

On-farm feeding and feed management strategies in tropical aquaculture

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Aquaculture and Aquatic Resources Management Field
Asian Institute of Technology
Thailand

Yakupitage, A. 2013. On-farm feeding and feed management strategies in tropical aquaculture. *In* M.R. Hasan and M.B. New, eds. *On-farm feeding and feed management in aquaculture.* FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. pp. 361–376.

ABSTRACT

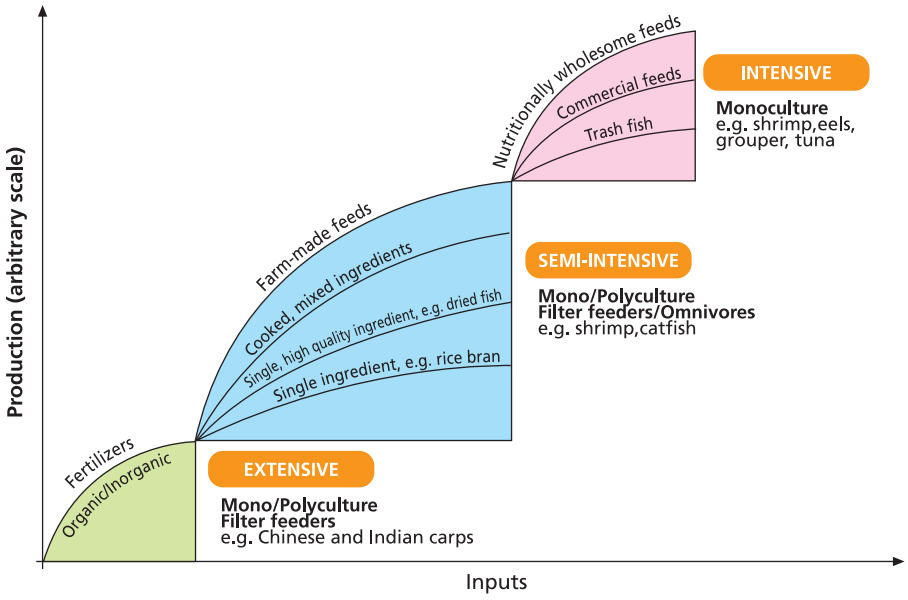
Aquaculture can be defined as the farming of aquatic organisms by controlling at least one stage of the life cycle. The life cycle controls are conceptually divided into larval, nursing, grow-out and broodstock management stages. At each stage, there are different feeding objectives. Those for the first-feeding larval stage are to wean fish larvae onto dry feeds while ensuring maximum survival. Farmer strategies include the use greenwater larval culture, either by fertilizing fish ponds or by culturing phytoplankton and/or zooplankton in tank systems or by initially feeding fish larvae with live feed and subsequently weaning them onto dry feeds. The feeding objective during the nursing stage is to culture postlarvae at relatively high densities to produce high-quality seed. The feeding strategies at the nursing stage are species-specific but generally consist of greenwater technology for omnivorous fish or the feeding of fish with farm-made or commercial feeds without deteriorating water quality. The carrying capacity at the nursing stage is determined mainly by water quality parameters. The feed and feeding management at the grow-out stage has been thoroughly reviewed. The main feeding objective during this stage is to reduce the feed conversion ratio (FCR), hence feed cost, and minimize feed/metabolic waste generation. Farmers may use either farm-made, semi-commercial or commercial feeds. Widely used feeding strategies in the grow-out stage are feeding the fish: (1) at 80–90 percent satiation (e.g. as in cage culture); (2) every other day (e.g. as in seabass pond culture); (3) at a high rate for a number of days and then at a lower rate for a number of days (or a variation of this strategy - as in e.g. Pangasius catfish culture); (4) by mixing greenwater technology and supplemented formulated feeds (e.g. in Nile tilapia pond culture); and (5) by using microbial floc technology (e.g. as in penaeid shrimp culture). The feeding objectives in broodstock management are to stimulate the development of good quality eggs to enhance hatching and larval survival rates. Since the nutritional requirements, especially the fatty acid requirements, of freshwater and marine fish differ, various feed mixtures and feeding strategies are used by farmers. The challenges for broodstock feed preparation are species-specific. Since information on the nutritional requirements of broodstock is scarce, suitable commercial feeds

for the maturation of marine fish are not widely available. Low-value fish/trash fish-based on-farm feed dominates in this sector. Farmers producing seed of low-fecundity fish such as Nile tilapia face the problem of enhancing egg output. The prices of traditional fish-feed ingredients, such as fishmeal, soybean meal, and cereal-based brans, follow a gradual and persistently increasing trend; hence both farm-made and commercial feed prices closely follow the flow of ingredient prices. Anti-nutritional and anti-stimulant factors prohibit the use of a higher percentage of less expensive ingredients in fish feed. The feed cost of semi-intensive to intensive fish culture ranges from 30 to 70 percent of the farm-gate price of the fish; farmers may face bankruptcy due to failures in related husbandry, such as water quality and health management. These issues and challenges, and the opportunities to respond to them, are discussed in this paper.

1. INTRODUCTION

Although fish farming has been practiced for more than 3 000 years, the expansion of tropical aquaculture took place only in the 1980s. Input resources and market availability were the driving forces of this expansion. Among the input resources, the development feed and feeding methods are major forces that pushed the formerly extensive finfish and crustacean aquaculture towards semi-intensive and intensive culture systems. This transition from extensive to intensive systems is shown schematically in Figure 1.

FIGURE 1
A schematic representation of the links between broad feed types, nutrition gained and the productivity of cultured stock



Source: De Silva and Hasan (2007).

The status of tropical aquafeeds and feed management has been thoroughly reviewed by various authors (e.g. New, Tacon and Csavas, 1993, 1995; Tacon and De Silva, 1997; Hasan, 2007; Williams, 2007; 2009; Tacon, Hasan and Metian, 2011). Hasan *et al.* (2007) conducted an extensive review of aquafeed management that addressed issues at the global, regional and country levels. Most of these reviews are focused on feed and feeding management at the grow-out stage, as the high feed cost during this period is of special concern. However, it is important to examine feed and feeding management in tropical aquaculture in a holistic way rather than focusing only on one particular life stage, as feed management practices at the grow-out stage will be governed by the early nutrition and feeding history of the fish.

2. AQUACULTURE AS A HUMAN-CONTROLLED ACTIVITY SYSTEM

The farming of aquatic organisms involves human control of at least one stage of the life cycle of the aquatic organism being cultured. Although aquaculture is sometimes termed 'culture fisheries' (Royce, 1996), it differs from capture fisheries by the degree of human intervention (Anderson, 2002; Asche and Khatun, 2006). The degree of human intervention or control is species-specific, i.e. humans either control the whole life cycle or a part of it. For example, in tropical aquaculture humans control the whole life cycle of many species, such as tilapia, Chinese and Indian carps, and pangasiid and clariid catfishes. However, in other species, such as the striped snakehead (*Channa striata*) and groupers (*Epinephelus* spp.), farmers collect wild fry and control only the grow-out stage. A different form of intervention is the collection of wild broodstock, such as is practised in the culture of black tiger shrimp (*Penaeus monodon*), and the control of the spawning to grow-out stages.

2.1 Aquaculture nutrition and feed management

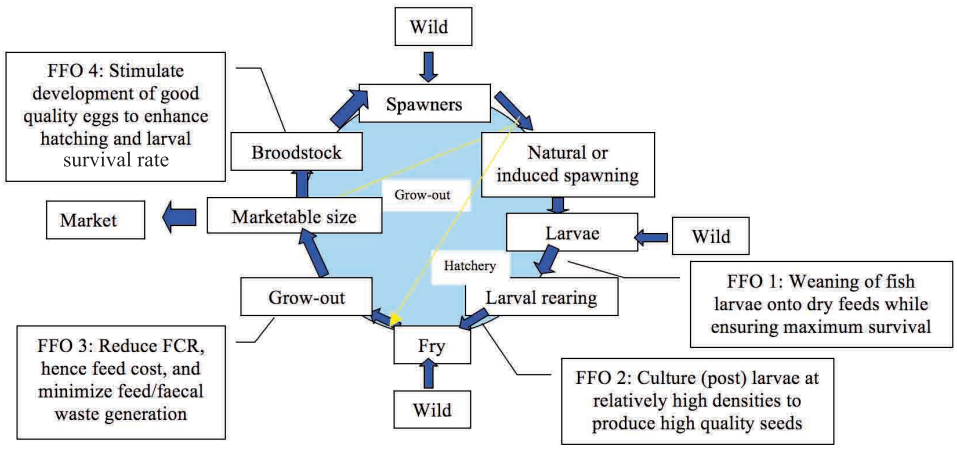
The husbandry of each stage in the life cycle of a fish includes four interrelated aspects:

1. culture units and water (quality and quantity) management;
2. standing stock management (including stocking and harvesting strategies);
3. aquatic animal health management; and
4. feed and feeding management.

The holistic view of aquaculture nutrition differs from fish nutrition *per se*. It involves paying attention to the details of all aspects of fish husbandry at every stage of the life cycle (i.e. broodstock, larval rearing, nursing and grow-out stages). Aquaculture feeding management has to be compatible with water temperature, dissolved oxygen, metabolic waste content, stocking density and fish health.

There are specific feed management objectives at each stage of the life cycle (Figure 2). Moreover, aquaculture feed and feeding management includes activities related to three major components: ingredients, manufacture, and on-farm feeding. Table 1 shows the major activities and farmer interests within each component. Farmers may engage in all or some of these activities, depending upon the choice of feed type (i.e. home-made/farm-made or commercial). This paper analyzes aquaculture feed management strategies in relation to the various life cycle stages, feeding objectives, farmer interests and related aspects of husbandry.

FIGURE 2
Schematic presentation of life cycle and general fish feeding objectives (FFO)



Source: This review.

TABLE 1

Components, activities and farmer/feed producer interests of aquafeed and feeding management systems

Component	Activities	Farmer/producer interests
Ingredient related	Selection, acquisition, storage, pre-processing	Nutrient composition, ingredient quality, particle size, grinding requirements, moisture content, storage requirements
Pellet/dough manufacture	Dietary nutritional specifications, formulation, processing of feed mixture, addition of feed additives, making of sinking or floating pellets, feed storage	Nutrient specification and feeding rate meeting nutrient requirements of fish, nutrient (amino acid, fatty acid, etc.) balance, digestibility, water stability
On-farm feeding	Feed storage, feeding regime (feed ration and feeding frequency), feeding method	Low FCR, low cost of feed, water stability, low feed and faecal waste, adequate water quality, disease-free, maximum survival and yield

2.2 Feed management at larval and fry stages

Reducing the dependence on trash fish/low-value fish from both fresh and marine waters is a priority for tropical aquaculture. In Cambodia, cage-cultured *Channa micropeltes* were fed entirely on small, wild, freshwater fish. Recently, the Cambodian Government banned cage culture of this species due to its potential threat to aquatic biodiversity of the Great Lake Ton Le Sap. Although there is a decreasing trend in the use of low-value fish during the grow-out stage of fish due to dwindling seasonal supply (Edwards, Tuan and Allan, 2004; Hasan and Halwart, 2009; Hasan, 2012), it is still the major ingredient, with an inclusion rate of 80–90 percent in feed mixes for carnivorous fish such as snakeheads (*Channa* spp.), groupers (*Epinephelus* spp.) and Asian seabass (*Lates calcarifer*). One of the specific characteristics of these aquaculture systems is their dependency on wild seed; except for Asian seabass, there is little or no hatchery-produced seed available.

A potential way of reducing trash fish/low-value fish use in aquaculture is to wean fish larvae and fry onto dry feeds. For example, until very recently, Asian seabass culture in Thailand depended entirely on trash fish as the main dietary ingredient (Thongrod, 2005), the feed conversion ratio (FCR) ranging from 5.5:1 to 7.5:1. Recent increases in marine trash fish prices and the availability of commercial feeds have driven farmers to rethink their feeding strategy (current trash fish price is THB9–11/kg (~US$0.3; therefore, if the FCR is assumed at 7:1 the total feed cost is THB63–77/kg of fish; the farm-gate price of fish is THB110–130/kg. Hatchery owners and farmers therefore started weaning hatchery-bred seabass larvae onto dry commercial feeds. Currently, the majority of farmers have abandoned the use of trash fish. The current commercial feed price is about THB37.5/kg and the observed FCR range from 2:1 in cage culture to 1.5:1 in pond culture (seabass farmers in Samutprakarn Province, personal communication, 2010). This results in a feed cost of THB56–75/kg of cultured fish produced. The costs of using trash fish and commercial pelleted feed are similar; the farmers' choice depends on the convenience of feeding and on the availability of trash fish (Hasan, 2012).

If the grow-out feeding strategy is to avoid dependence on trash fish, the major objective of larval (hatchery-bred) and fry (wild-collected) feed management should be the development of suitable methods to wean fish larvae and fry onto dry feeds. However, there are several issues to be addressed in developing suitable weaning procedures. Firstly, the feeding strategy at the larval stage should be related to the ontogenetic development of the digestive tract of the particular group of fish. Fish larvae are categorized into three groups according to the ontogenetic development of the digestive system (Dabrowsky and Portella, 2006): fish larvae with a distinct stomach (e.g. cichlids); stomachless fish with complex intestinal coiling patterns (e.g. cyprinids); and stomachless fish that develop a stomach gradually after initial food ingestion (e.g. silurids). Secondly, cannibalism (hence low survival rate) is a major problem during the weaning period. Reduction of cannibalism in the larvae of various fish species is

sought by providing attractive live feeds (Hung *et al.*, 2002); the feeding of live and artificial feed mixtures at an adequate rate (Evangelista, Fortes and Santiago, 2005); and stocking fish larvae at an optimal density, using appropriate light regimes and colours (Giri *et al.*, 2002). Thirdly, fish fry collected from the wild are often infected with parasites, and there is a need to develop suitable treatments to enhance survival rates. Although high growth rate of fish larvae is desirable, it is not a major concern at this stage.

2.2.1 Development of weaning methods

First-feeding of fish larvae with developed stomachs is straight forward, as species such as tilapia can be fed directly with dry feed. The most cost-effective feeding strategy for stomachless cyprinids is to stock first-feeding fish larvae into fertilized ponds, as practiced in the farming of both Indian and Chinese carps. However, the weaning of fish larvae that gradually develop a stomach is a challenge; there are several approaches for weaning these onto artificial dry feed. Hung *et al.* (2002) found that basa catfish (*Pangasius bocourti*) can be weaned onto trout pellets by feeding *Artemia* nauplii for the first three or more days and then feeding with standard artificial feeds. Co-feeding (i.e. combining live feed and artificial feed in the same meal) has been successfully used for weaning temperate fish larvae onto dry feeds. In this method, first-feeding commences with exclusively live feeds; a mixture of live and artificial feeds is then introduced; and finally all live feed is withdrawn (Rosenlund, Stoss and Talbot, 1999; Cañnvate and Fernández-Díaz, 1999; Bakerville-Bridges and Kling, 2000; Puvanendran, Burt and Brown, 2006; Faulak and Halt, 2009).

Research conducted at the Asian Institute of Technology (AIT) used a different approach for weaning fish larvae onto dry feeds. Firstly, a feeding trial was conducted to determine the best type of live feeds based on availability and cost. Secondly, a daily feeding regime consisting of five meals was set up for weaning larvae onto dry feeds. Feeding frequency was five times a day. At the beginning of the weaning trial, the feeding regime consisted of live feed (5 live : 0 dry feed) and then a gradually introduced number of dry feed meals (4L : 1D; 3L : 2D; 2L : 3D; 1L : 4D and 0L : 5D; L = live feed and D = dry feed). Each feeding regime changed at 1, 2, 3 or 4 day intervals (Table 2).

The results of some live feed selection trials are summarized in Table 3 and Figure 3. It was found that stinging catfish (*Heteropneustes fossilis*), whisker catfish (*Phalacronotus bleekeri*) and clown featherback (*Chitala ornata*) preferred *Moina*, *Tubifex* and chironomid larvae, respectively. All three species were able to wean onto dry feeds by changing the feeding regime every three days (i.e. within a total of 15 days).

TABLE 2

Feeding regime used to wean fish larvae onto dry feed at the Asian Institute of Technology

Feeding regime		Control treatments		Weaning treatments			
No. of live feed meals per day	No. of dry feed meals per day	Number of days of offering each feeding regime					
		Live feed control	Dry feed control	1	2	3	4
5	0	28	–	1	2	3	4
4	1	–	–	1	2	3	4
3	2	–	–	1	2	3	4
2	3	–	–	1	2	3	4
1	4	–	–	1	2	2	3
0	5	0	28	23	18	13	8
Total acclimatization period for weaning onto artificial feed (days)		0	0	5	10	15	20
Total experimental duration (days		28	28	28	28	28	28

Source: Dan (2008); Samphawamana (2009); Munsiri (2010).

TABLE 3

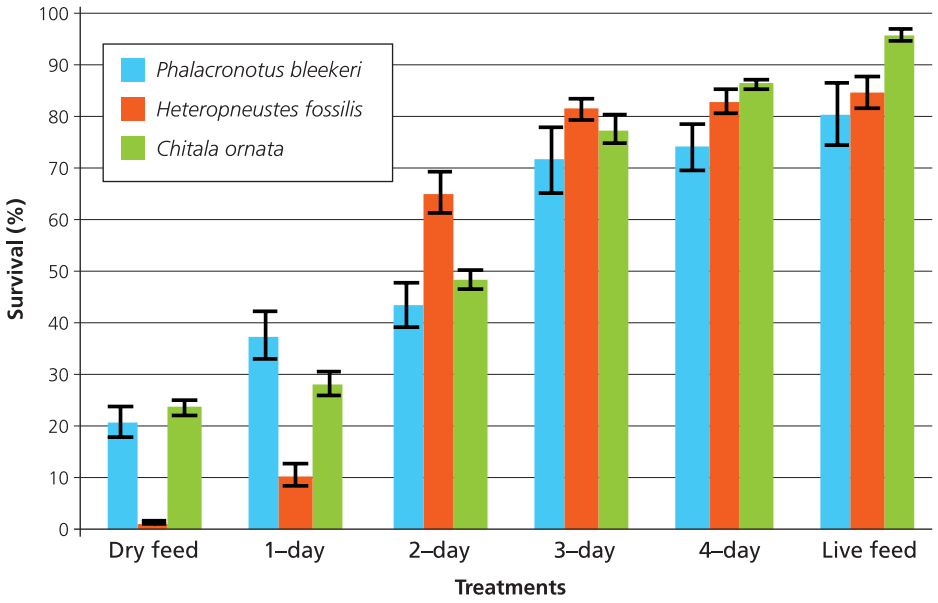
Growth and survival rate of larvae of stinging catfish (Heteropneustes fossilis), whisker catfish (Phalacronotus bleekeri) and clown featherback (Chitala ornata) fed on different live feeds for 21 days (mean ± standard deviation; different superscripts in the same column indicate significant differences at P< 0.05 based on Tukey's HSD)

Zooplankton	Criteria	Stinging catfish larvae fry[1]	Whisker catfish larvae[2]	Clown featherback larvae[3]
Artemia	SGR (%/day)	30.00±1.0b	22.3±0.2b	8.14±0.11b
	SR (%)	84.06±3.1a	80.3±6.4a	95.00±0.86b
Moina	SGR (%/day)	31.63±1.0a-graded	22.1±0.2b	6.80±0.09d-ungraded 7.36±0.07c-graded
	SR (%)	86.87±1.8a-graded	61.0±5.95b	39.3±0.54d-ungraded 46.3±0.86c-graded
Rotifer + Artemia + Moina	SGR (%/day)	30.65±0.5ab	–	–
	SR (%)	83.81±3.0a	–	–
Rotifer	SGR (%/day)	26.95±0.4c	–	–
	SR (%)	63.25±3.3b	–	–
Tubifex	SGR (%/day)	–	23.8±1.0a	–
	SR (%)	–	82.8±9.2a	–
Chironomus	SGR (%/day)	–	21.9±0.5b	9.40±0.11a
	SR (%)	–	15.8±1.7c	97.00±0.86a

Source: [1]Samphawamana (2009); [2]Dan (2008); [3]Munsiri (2010).

FIGURE 3

Weaning of larvae of stinging catfish (*Heteropneustes fossilis*), whisker catfish (*Phalacronotus bleekeri*) and clown featherback (*Chitala ornata*) onto dry feeds



Notes: At the beginning of the weaning trials, the feeding regime consisted of live feed (5 live : 0 dry feed) and then a gradually introduced number of dry feed meals (4L : 1D; 3L : 2D; 2L : 3D; 1L : 4D and 0L : 5D); L = live feed and D = dry feed; each feeding regime changed at 1, 2, 3 or 4 day intervals (see Table 2).
Source: Dan (2008) Samphawamana (2009), Munsiri (2010).

2.2.2 Parasitic infection of wild-caught fry

Stocking of wild-caught fish fry is a general practice in snakehead (*Channa striata*) and grouper (*Epinephelus* spp.) culture in Thailand. Low-value marine fish are used as a major feed ingredient (80–90 percent) during both fry rearing and the grow-out stage. The weaning of wild-collected fry onto dry formulated feeds is problematic due to heavy mortality during the process. An initial attempt to wean snakehead fry onto dry feed using a commercial frog feed showed the survival rate was as low as 38 percent (Khundech, 2008).

Thai farmers believe that the application of 'Rotab worms' (General Drugs House Co. Ltd, Bangkapi, Bangkok; contains piperazine citrate) is an effective treatment for wild fish fry infected with endoparasites during the weaning process. Haque (2009) conducted a weaning trial to investigate whether Rotab is an effective treatment for weaning wild-collected snakehead fry onto dry feeds and found that it improved survival.

2.3 Feed and feeding management at the grow-out stage

Fish feeds in tropical Asia are generally categorized into three types (De Silva and Hasan, 2007):

- Farm-made feeds
  - Semi-commercial feeds
  - Custom-made feeds for a particular (farmer-specified) nutritional specification
- Feeds manufactured on-farm and sold to neighbouring or contract farmers
- Commercial feeds

Farm-made feeds for the grow-out stage are related to all three components shown in Table 1, namely ingredient related, feed manufacture and feeding on the farm. De Silva and Hasan (2007) defined farm-made feed as the use of ingredients of plant or animal origin, either singly or in combination with other ingredients, but with little or no processing or as a mixture of ingredients that is subjected to some processing. This definition does not cover on-farm feed produced in feed mills located on the farm premises. The latter type is similar to that produced by commercial feed manufacturers but with the use of less sophisticated equipment.

The composition of farm-made feed is based on the purpose of culture. Rural farmers who culture fish for family consumption and to sell excess fish to a local market usually use ingredients of plant or animal origin, either singly or in combination with other ingredients but with little or no processing, as mentioned by De Silva and Hasan (2007). Those who produce on-farm feed for fish such as snakehead, pangasiid catfish, seabass and groupers primarily use animal by-products (e.g. chicken processing waste), trash fish (80–90 percent) or fishmeal (40–50 percent) mixed with plant ingredients, such as rice bran.

2.4 Feed and feeding strategies at the broodstock stage

The most important limiting factor in the mass production of high-quality fish seed is the unpredictable variability of broodstock performance (Izquierdo, Fernández-Palacios and Tacon, 2001). Food restrictions and reduced feed ration inhibit gonadal maturation and delay spawning time. Although our knowledge on broodstock nutrition is still in its infancy, published data on the nutritional requirements of cultured fish exist. Watanabe (1982) showed that the number of fry per spawning and the total fry production were high in Nile tilapia fed a basal diet supplemented with soybean oil that was high in n-6 fatty acids. However, there is no single feed in the market specifically designed for Nile tilapia broodstock. Bhujel *et al.* (2001) conducted a trial to select a grow-out feed for Nile tilapia broodstock and found that catfish pellets are more effective than the herbivorous fish feed available on the Thai market. These authors attributed the higher seed production of fish fed catfish pellets to higher protein content (25 percent) and small pellet size.

Thai seabass farmers have developed their own feeding strategy for seabass broodstock. The main feed ingredient is fresh marine fish with a low fat content.

Bigeye scad (*Selar crumenophthalmus*) is considered as the best low-value fish for broodstock feeding. Bigeye scad is injected with a mixture of vitamin E (30 – 50 mg/kg), vitamin B-complex and vitamin C (100 mg per fish)[1]. In contrast, INVE Aquaculture has produced a special dietary additive (Fish Breed-M) for Asian seabass and a vitamin mix. The additive and vitamin mix are injected into whole mullet and squid. Fish are fed with 10 and 20 cm pieces of fish or squid for three days a week (Schipp, Bosmans and Humphrey, 2007). The need for development of broodstock feeds for tropical fish culture should not be neglected, as high-quality fish seed is a function of good quality eggs.

2.5 Use of fishmeal and fish oil in tropical Asian aquaculture

The use fishmeal and fish oil in formulated feed for fish and crustacean culture has been much debated since 1995 (e.g. New and Csavas, 1995; New and Wijkstrom 2002: Tacon, 2004; Pike, 2005; Tacon, Hasan and Subasinghe, 2006; Deutsch *et al.*, 2007; Tacon and Metian, 2008; Schipp, 2008; Tacon, Hasan and Metian, 2011). The major concerns are that use of fishmeal and trash fish/low-value fish in aquaculture may threaten human food security *via* direct competition, threaten aquatic biodiversity, and pose risks to the sustainability of capture fisheries.

Deutsch *et al.* (2007) claimed that shrimp feeds in Thailand use fishmeal at inclusion rates of 30–40 percent. Table 4 shows the maximal and minimal inclusion rate of fishmeal and fish oil in aquaculture feed in tropical Asian countries (selected data from Tacon and Metian, 2008). Commercial feed formulae for greasy grouper (*Epinephelus tauvina*). black tiger shrimp (*Penaeus monodon*) and striped catfish (*Pangasius hypophthalmus*) are shown in Table 5. These data show that the maximum percentages of fishmeal used in feeds for marine finfish, shrimp and freshwater prawn culture is greater than for the other species listed. In fact, freshwater prawns are omnivores and studies in the United States of America have shown that the giant river prawn, *Macrobrachium rosenbergii*, thrives on, for example: commercial channel catfish feeds containing no fishmeal or oil; standard cattle feeds; and (at low stocking densities) on experimental diets based on distillers dried grains with no fishmeal (D'Abramo and New, 2010). It appears than fishmeal usage in the freshwater prawn diets used in Asia could be beneficially reduced.

Omnivorous fish culture uses a relatively small amount of fishmeal or fish oil. Semi-commercial fish feed manufacturers in the Mekong Delta use fishmeal at rates as low as 4 percent, without the addition of any fish oil. Tropical aquaculture is dominated in volume by omnivorous fish species. It is very likely that this trend will continue in the future; hence, the reliance of tropical aquaculture on fishmeal and fish oil should be negligible.

TABLE 4
Estimated fishmeal and fish oil use in fish and shrimp feeds in tropical Asia

Feed type	Fishmeal (%)	Fish oil (%)
Marine shrimp	5–35	0.5–6
Asian seabass/grouper	20–50	2.5–6
Freshwater prawns	5–25	0–3
Tilapia	0–20 (usually 10)	0–3
Milkfish	1–5	0–2
Chinese carps	0–10	0
Pangasiid catfish	5–20	1–3

Source: Tacon and Metian (2008).

[1] Exact quantities of vitamins are unknown; information derived from personal communications with seabass farmers.

TABLE 5
Some ingredients (%) and aquafeed formulations use in Asia for juvenile groupers, black tiger shrimp and striped catfish

Ingredient	Juvenile grouper[1]	Black tiger shrimp[2]	Striped catfish[3]
Fishmeal	28	25.8 (16.0% Chile + 5.8% Denmark+ 4.0 local)	4
Shrimp head meal	10	–	–
Squid meal	2	1.9 (dried squid)	–
Squid liver powder	3	5.1	–
Meat meal or meat soluble	–	2.9	4
Blood meal	–	1.7	2
Wheat gluten	6	4.4	–
Wheat flour	20	29.8	–
Cassava starch	–	–	4
Soybean meal	10	6.4	25
Broken rice	10	–	8
Rice bran (RB)	–	–	48 (50% of RB defatted)
Fish oil	2	–	–
Squid liver oil	–	0.4	–
Chicken eggs	–	1.7	–
Lecithin	–	1.0	–
Vitamin mixture	1.0	0.8	–
Mineral mixture	4	1.9	0.5 mineral+vitamin mix; 1% DCP[5]
Amino acid mixture	–	–	0.5
Recovered feed[4]	–	13.4	–
Others (binders, feed stimulants, aflatoxin inhibiters, salt, etc.)	2–4	2.8	1–3

Source: [1]Boonyaratpalin (1993); [2]A commercial feed formula in Thailand; [3]Semi-commercial (farmer-made) striped catfish feed in the Mekong Delta, Viet Nam; [4]Feed waste recovered from the previous batches of production; [5]DCP = di-calcium phosphate.

3. REDUCING FEED COSTS

Edwards, Tuan and Allan (2004), who conducted a survey of feed use in the Mekong countries, stated that the single largest issue emerging from the survey is how to reduce feed costs. They further mentioned that small-scale farmers rarely used commercial feeds. Although farmers agreed that the use of commercial feeds is the most effective way to culture fish, the cost of production exceeds the farm-gate price.

Yang and Yakupitiyage (2001) summarized the reported types of feed, protein content and FCR values used in small-scale aquaculture (Table 6). Moving from unprocessed ingredients to commercial feeds resulted in improvements in FCR. For this reason, and also due to enhanced growth rates, commercial feeds are becoming popular in tropical fish farming.

TABLE 6

Feeds used in the grow-out stage of fish culture, crude protein content and reported range of feed conversion rate (FCR) values if given directly to the fish

Feed type	Crude protein content (% dry matter basis)	FCR
Aquatic plants	15–35	20:1–100:1
Terrestrial plants	10–30	20:1–50:1
Aquatic and terrestrial animals (excluding fish)	>40	10:1–80:1
Agricultural by-products		
De-oiled cakes	20–50	3:1–6:1
Beans	25–36	4:1–8:1
Grains/brans	8–27	3:1–4:1
Animal products and by-products	>40	1.5:1–4:1
Formulated feed – wet dough	18–50	5:1–8:1
Formulated feeds – dry feeds (usually farmer-made)	18–50	1.5:1–4:1
Commercial feeds	18–40	1:1–2:1

Source: Modified from Yang and Yakupitiyage (2001).

Low FCR does not always guarantee a low total feed cost, however, as the latter is a function of both the feed unit price and FCR. However, the major feeding objective of farmers who use farm-made and commercial feeds is the reduction of FCR, as the ingredient and feed prices are beyond their control. This is usually achieved *via* various husbandry strategies, including controlling the feeding regime. Widely used feeding strategies in the grow-out stage are:

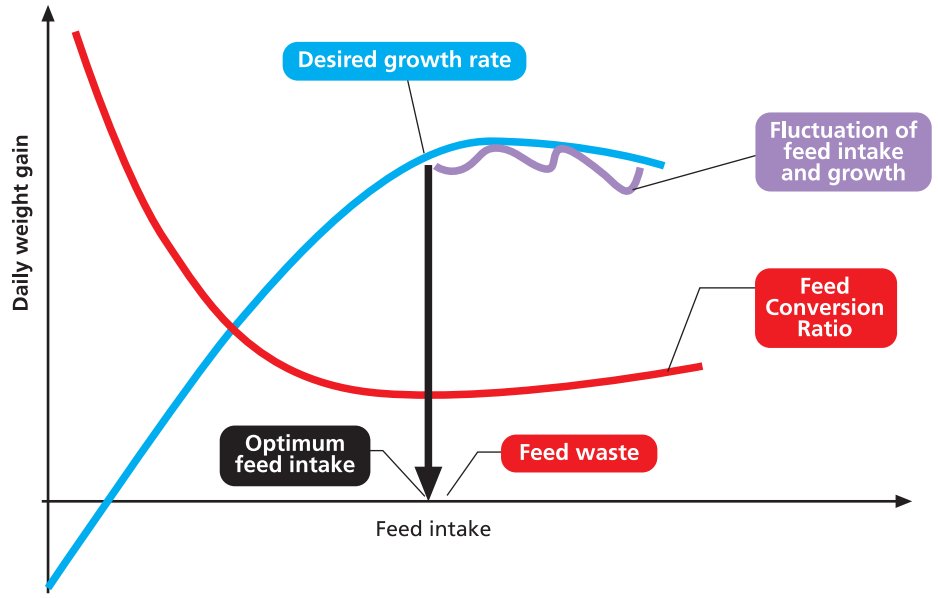
- feeding just below satiation, e.g. 80–90 percent satiation feeding in Nile tilapia cage culture (personal communication with Thai farmers, 2009);
- high protein diet (De Silva, 1985) or high feeding rate (Patel and Yakupitiyage, 2003) for a number of days, followed by low protein diet or low feeding rate for a number of days;
- feeding frequency manipulation (e.g. in marine shrimp culture: Smith *et al.,* 2002; Carvalho and Nunes, 2006) or feeding every other day (e.g. in seabass pond culture in Thailand (personal communication with seabass farmers, 2009);
- growing fish in greenwater with supplementary feeding, either using formulated or commercial feeds (e.g. Nile tilapia pond culture (Diana, Lin and Jaiyen, 1994); and
- bio-floc technology (e.g. for penaeid shrimp (Burford *et al.,* 2004; Taw *et al.,* 2009) and Nile tilapia (Avnimelech, 2007; Little *et al.,* 2008).

3.1 Feeding just below satiation and mixed feeding schedules

Feeding just below satiation is a feeding strategy widely used by farmers. The rationale for this strategy is that farmers observe that on some days fish eat all the feed given, while on other days they leave some feed uneaten. Figure 4 shows a schematic representation of the relationship between feed intake, growth and FCR. FCR decreases until fish are fed at an optimal feeding rate. Feed intake, hence growth, starts to fluctuate at the highest feeding rates, and FCR begins to show an increasing trend. Feed waste generation starts when fish are fed above the optimal feed intake.

There are two solutions to this feed intake fluctuation issue: feed at just below satiation; or develop mixed feeding schedules. Feeding at just below satiation requires weekly or biweekly determination of the satiation feeding level, which is a cumbersome practice. De Silva (1985) suggested a mixed feeding schedule where alternating presentation of diets containing 30 percent protein and 18 percent protein resulted in improved nutrient utilization. This was further demonstrated by Hashim (1994) for

FIGURE 4
Schematic presentation of feed intake and growth of a particular sized fish



Source: This review.

Channa striata, Saha and Ray (1998) for rohu, *Labeo rohita*, Nandeesha *et al.* (1994) for Indian major carps and Nandeesha, De Silva and Krishnamurthy (1995) for common carp, *Cyprinus carpio*. Patel and Yakupitiyage (2003) developed a feeding system for Nile tilapia weighing 30–150 g based on a mixed feeding schedule, alternately feeding 2.3 percent body weight (BW) per day and 1.5 BW per day; these authors found that 2 days of high feeding rate followed by 3 days of low feeding rate significantly improved protein utilization efficiency without any significant decline in net fish yield or daily weight gain. De Silva (2010) reported that mixed feeding schedules based on changing the rate of feeding on a daily basis are attracting more attention among catfish farmers in Viet Nam.

3.2 Feeding frequency

Feeding frequency is a function of the daily nutrient requirements of the animal, the nutrient content (specification) of the feed, the digestibility coefficient of the feed, the ingestion rate, the gastric capacity and the water stability of the pellets. Rowland *et al.* (2005) showed that the feeding frequency of silver perch (*Bidyanus bidyanus*) is a function of ration size. Adjustment of feeding frequency is more important for slow-feeding animals such as marine shrimp and freshwater prawns than for aggressively feeding fish.

Nutrient leaching is a major reason for increasing feeding frequency. However, there are major differences between farmer practices and scientific recommendations. Smith *et al.* (2002) reported that 15 percent of nitrogen losses occur during the first two hours of immersion of *Penaeus monodon* feed pellets. Carvalho and Nunes (2006) observed that crude protein and lipid levels reduced from 39.58 percent to 34.07 percent and from 9.25 percent to 7.88 percent, respectively, after eight hours of water immersion of pelleted feed for the whiteleg shrimp *Litopenaeus vannamei*. FCR was not reduced by increasing feeding frequency more than three times a day for *P. monodon* or 5 times a day for *L. vannamei*. However, black tiger shrimp farmers feed their animals five to six times a day. This is probably due to the fact that the laboratory experimental conditions do not reflect the on-farm commercial practices of feed management employed by shrimp farmers.

3.3 Growing fish in greenwater and supplementary feeding

Diana, Lin and Jaiyen (1994) found that feeding Nile tilapia at 50 percent satiation in fertilized ponds (i.e. greenwater) produced a yield comparable to fish fed at 100 percent satiation. The most economical way of supplementary feeding in fertilized ponds at a stocking density of 3/m² was found to be when feeding was started when the fish reached 100 g. The observed FCR was 0.75:1–1:1 (Diana, Lin and Yang, 1996). This type of feeding strategy is applicable to omnivorous fish culture.

3.4 Bio-floc technology

Bio-floc technology (BFT) is alternatively termed as microbial-floc technology (MFT) or activated suspension technology (AST). The basic principle is the production of microbial flocs that attach to each other (Burford *et al.*, 2004). These microbial-flocs either float or are suspended at the bottom and become a nutritious food for fish. Added advantages of this system are that the protein content of the feed provided can be reduced without resulting in a high FCR, and the feed waste can be minimized. However, production of microbial-flocs depends on the qualitative and quantitative supply of external organic substrates, such as molasses and carbohydrate-rich feed and internal waste from fish excretion to the microbial community (Avnimelech, 2007). Although there is no general agreement, the carbon to nitrogen (C/N) ratio is considered to be higher than 10:1. The biodegradation rate is dependent upon the microbial community composition. The system needs continuous aeration; therefore there is a relatively high investment cost. FCR values observed in commercial and experimental bio-floc systems are shown in Table 7.

TABLE 7

Growth rate (DWG or SGR) and feed conversion ratio (FCR) observed in bio-floc systems

	Species	DWG (g)	SGR (%)	FCR	System[1]	Reference
Bio-floc	*Litopenaeus vannamei*	0.16	–	1.1:1–1.24:1	C + P	Taw *et al.* (2009)
Greenwater	*L. vannamei*	–	–	1.6:1	C + P	Taw *et al.* (2009)
Bio-floc (AST)	*Oreochromis niloticus*	3.6	2.8	1.1:1	E + T	Little *et al.* (2008)

[1]C = commercial; P = ponds; E = experimental; T = tanks.

4. CONCLUSIONS

The aquaculture industry grew at a rapid rate during the last two decades of the twentieth century, and this trend has continued in the first decade of the new millennium. It is widely agreed that nutrition and feeding have played a central role in the development of aquaculture (Hasan, 2001); however, further increases in aquaculture production are constrained by the rising costs of feed ingredients and feeds. Feed management strategies such as feeding just below satiation, mixed feeding schedules, the use of optimal feeding frequency, feeding every other day (especially for carnivorous fish), growing fish in greenwater with supplementary feeding, and bio-floc technology have been successfully used to reduce feed costs at the grow-out stage of fish culture. However, there is a paucity of information on farmer feeding practices and hence a concerted effort is needed for both data gathering and the information transfer of promising feeding practices. The debate surrounding the use of fishmeal and fish oil use in aquafeeds will continue. Although omnivorous fish dominate tropical aquaculture and use a negligible amount of fishmeal, research aimed at further reduction of the use of low-value fish and fishmeal in aquafeeds is warranted.

Broodstock and larval nutrition and feed requirements remain the least understood thematic area of aquaculture nutrition. This knowledge gap is reflected by the absence of commercial broodstock and weaning feeds in the markets. Seed quality is a function of the nutritional history of both broodstock and larvae; thus placing more emphasis on improving seed nutrition will assist in enhancing survival, and hence the yield, at the grow-out stage of fish culture.

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Tilapia feed management practices in sub-Saharan Africa

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ABSTRACT

Tilapia is a traditional source of nutrition for the general population in many countries in sub-Saharan Africa (SSA). However, farmed tilapia production in SSA is relatively low, representing only about 2.5 percent of global tilapia production in 2010. At the continental level, the Arab Republic of Egypt was the largest contributor to African tilapia culture (86.3 percent) in 2010, while SSA contributed only 13.7 percent. This review considers only those SSA countries whose tilapia production exceeds 500 tonnes per year: the Republic of Côte d'Ivoire, the Democratic Republic of Congo, the Republic of Ghana, the Republic of Kenya, the Republic of Malawi, the Federal Republic of Nigeria, the Republic of the Sudan, the Republic of Uganda, the Republic of Zambia and the Republic of Zimbabwe. Tilapia culture in SSA has recently been growing at an outstanding rate, increasing during the period 2006 to 2010 from 39 883 tonnes to 88 238 tonnes/year. Tilapia culture in SSA is mainly a small-scale, semi-intensive activity, practiced mainly by non-commercial farmers in freshwater earthen ponds. Medium and large-scale, intensive cage culture is also practiced in a few countries (e.g. Ghana, Malawi and Zimbabwe). Semi-intensive production relies on pond fertilization and enhanced natural food. Composts, chicken manure, cattle manure or pig manure are generally applied. Both urea and di-ammonium phosphate (DAP) are also used for pond fertilization. Ingredients suitable for tilapia feed manufacture are available in most of the region. However, aquafeed mills are few, and commercial feed production is limited because the demand for commercial fish feed is too low to justify industrial-scale production. Therefore, commercial tilapia feeds are only manufactured in a few SSA countries (Cameroon, Kenya, Malawi, Nigeria, Zambia and Uganda). The high transport costs and quality issues with locally manufactured diets force fish farmers to rely on imported pelleted feeds or farm-made feeds. Data on commercial feed costs are provided in this review. Farm-made tilapia feed is widely used in the whole region, particularly in Nigeria, Uganda and Zambia. Over 100 000 tonnes of farm-made feeds are currently produced annually, mostly fed to tilapia in the form of dry pellets, formulated mash or formulated wet dough. Feeding tilapia with only cereal bran (corn, rice and wheat) is also common, especially among small-scale, non-commercial farmers in rural areas who produce tilapia mainly for family

subsistence. Feeding is carried out once or twice daily, depending on fish size and pond conditions. Manual feeding is the most common feeding method in all SSA countries. However, the use of automatic feeders or demand feeders has been successfully tested in tilapia cage culture in Ghana and Malawi. The main constraints faced by tilapia farmers and the tilapia feed industry in SSA include the escalating price of ingredients and finished feeds, high transportation costs, poor transport and storage infrastructure, limited commercial feed production due to low demand, poor quality of locally produced feeds and limited research on tilapia feeds and feeding under local conditions. In order to tackle these problems, the SSA governments should: stimulate domestic feed industries by reducing or removing taxes on imported feed milling machinery and basic feed ingredients, provide low-interest loans to producers, ensure feed quality and safety through inspections and feed certification, promote the adoption of appropriate feed manufacturing guidelines and standards, provide the necessary extension services and training on the best feeding and fertilization practices, develop country-specific farm-made feed formulations and promote research on tilapia nutrition and feed management, with emphasis on nonconventional feed ingredients. On the other hand, commercial feed producers should produce and market necessary feedstuffs to fish farmers, provide high-quality feeds at reasonable prices, make proximate analyses available to clients and provide information on feed availability and efficacy to the public sector.

1. INTRODUCTION

Tilapias are a group of freshwater fish species originating exclusively from Africa (Philippart and Ruwet, 1982; El-Sayed, 2006). They are distributed throughout Africa, except for the northern Atlas Mountains and southwest Africa (McAndrew, 2000). Outside Africa, tilapia were introduced into many tropical, subtropical and temperate regions of the world during the second half of the twentieth century (Pillay, 1990; El-Sayed, 2006). Tilapia can live in various ecological systems, including slow-moving rivers and their flood-plain pools and swamps, small shallow lakes, large deep lakes, impounded waterbodies, isolated crater lakes, soda lakes, thermal springs and brackishwater lakes (Philippart and Ruwet, 1982; Lowe-McConnell, 2000). They have many attributes that make them ideal candidates for aquaculture, including their fast growth, tolerance to a wide range of environmental conditions (e.g. temperature, salinity, low dissolved oxygen, etc.), resistance to stress and disease, ability to reproduce in captivity, short generation time, feeding at low trophic levels and acceptance of artificial feeds immediately after yolk-sac absorption.

It is believed that tilapia culture was practiced in Egypt about 4 000 years ago, as illustrated from ancient Egyptians tombs (Balarin and Hatton, 1979). Tilapia culture has rapidly expanded throughout the world in recent years, so that tilapia are currently cultured in about 100 countries. As a result, the global production of farmed tilapia has increased more than 900 percent during the past two decades, jumping from 383 654 tonnes in 1990 (representing 2.28 percent of total aquaculture production) to reach 3 497 391 tonnes in 2010 (4.43 percent of total production). The average annual growth of tilapia production during that period approached 13 percent. Thus, tilapia rank second in terms of global production, after carps (Fitzsimmons, 2008).

Tilapia have been traditionally cultured semi-intensively, at small-scale levels, in different parts of the world, either in monoculture or in polyculture with other herbivorous/omnivorous fishes, such as carps and mullets. However, the rapid industrialization of tilapia production in recent years has led to a gradual shift from low-input, semi-intensive culture (SIC) to more intensive farming practices, with an increasing dependence on formulated feeds (El-Sayed, 2006, 2007).

Therefore, the major challenge facing the tilapia culture industry is the production of sufficient amounts of quality seed. The formulation of appropriate feeds in order to optimize reproductive outputs, seed production and growth performance is also a key factor for promoting tilapia culture. Commercial tilapia culture is currently restricted to about 10 species. However, Nile tilapia (*Oreochromis niloticus*) (particularly all-male fish) is the most important farmed tilapia species globally. The production of farmed Nile tilapia represented more than 75 percent of the total production of farmed tilapia in the period 1970 to 2010.

2. TILAPIA CULTURE IN SUB-SAHARAN AFRICA

Geographically, sub-Saharan Africa (SSA) is the area of the African continent which lies south of the Sahara. It includes 46 countries (Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Togo, Uganda, United Republic of Tanzania, Zambia and Zimbabwe). The Horn of Africa and Sudan are geographically part of sub-Saharan Africa, but they are also part of the Arab world. The sub-Saharan region is characterized by an extremely harsh climate.

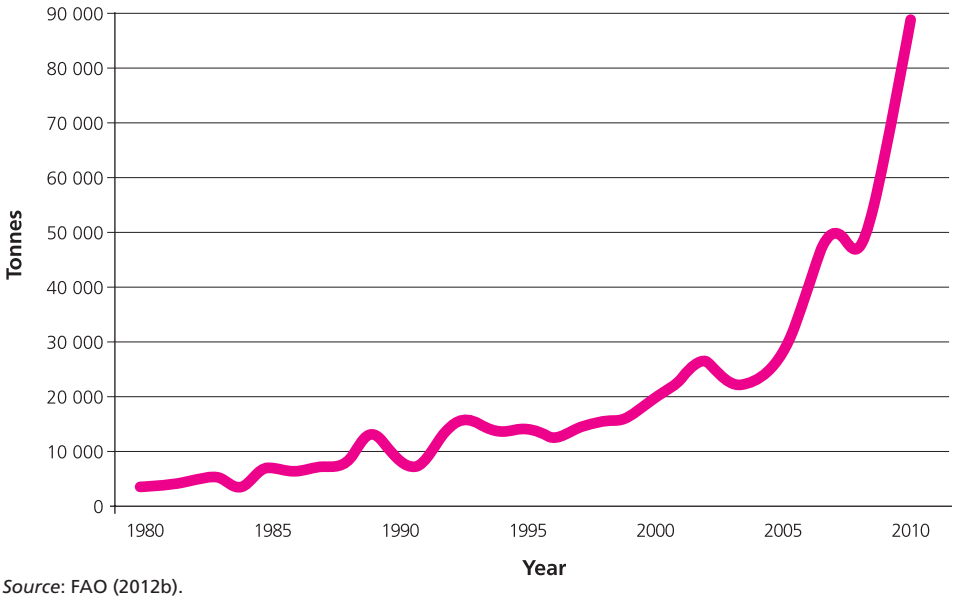
Aquaculture in SSA dates back to the 1920s, when trout breeding was introduced into Kenya and Madagascar, and later into Tanzania. However, in spite of this long history, aquaculture still remains marginalized, with limited contribution to national economies. Aquaculture in SSA contributes 0.63 percent and 34.95 percent to total world and African aquaculture production, respectively (FAO, 2012b).

Tilapia have been, and still are, the target species for aquaculture in many sub-Saharan countries. These fish make a significant contribution to food security in rural areas. Small-scale non-commercial tilapia farms vastly outnumber commercial farming enterprises. Despite the fact that tilapia are African fish, tilapia culture in SSA is relatively new, with a low contribution to both global and African tilapia production (2.5 and 13.7 percent, respectively in 2010; FAO, 2012b). Farmed tilapia production in SSA, however, has sharply increased during the past few years (Figure 1). Generally, this trend in tilapia production can be divided into three phases:

- **1980–1995**: during this period, the production of tilapia grew slowly and intermittently.
- **1996–2005**: tilapia production soared to 27 630 tonnes by 2005.
- **2006–2010**: tilapia production witnessed a huge increase, reaching 88 238 tonnes by 2010. Further increase in production is expected, due to the expansion of tilapia culture in several SSA countries.

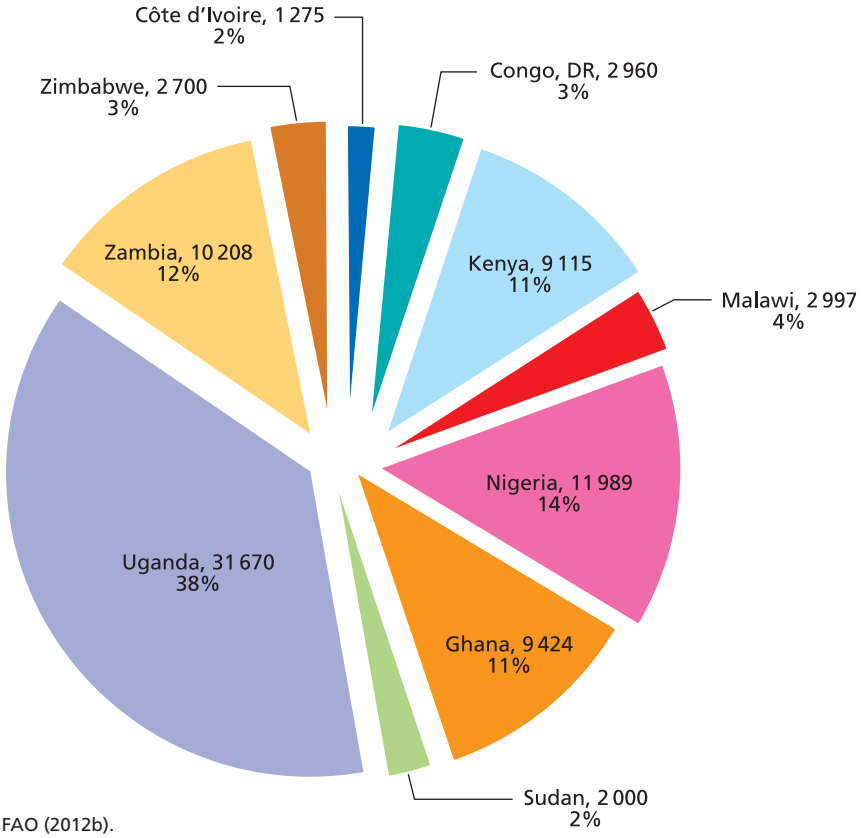
This review can be considered a sequel to previous studies undertaken in 2001 (Shipton and Hecht, 2005) and 2007 (Hecht, 2007). However, this review is more specific, since it focuses on feed management practices for tilapia alone, not the whole aquaculture sector in SSA. For comparison and where appropriate, information on tilapia feeding and feed management from other African countries is also presented. This review has considered only the SSA countries whose annual tilapia production exceeds 500 tonnes per year: Côte d'Ivoire, DR Congo, Ghana, Kenya, Malawi, Nigeria, Sudan, Uganda, Zambia and Zimbabwe. The tilapia production of these countries represents 95 percent of total tilapia production in the region; the proportion produced by each of these ten countries in 2010 is shown in Figure 2.

FIGURE 1
Production of tilapia in sub-Saharan Africa, 1980–2010



Source: FAO (2012b).

FIGURE 2
Tilapia production by the ten major producing countries in the sub-Saharan Africa region in 2010



Source: FAO (2012b).

2.1 Cultured tilapia species

In all selected sub-Saharan countries, except Malawi, Nile tilapia (*Oreochromis niloticus*) is the dominant cultured cichlid species (Table 1). Nile tilapia has been excluded

from Malawian waters and replaced with Mozambique tilapia (*O. mossambicus*), chambo (*O. shiranus shiranus* and *O. karongae*) and redbreast tilapia (*Tilapia rendalli*). Longfin tilapia (*O. macrochir*) and redbreast tilapia are also widely cultured elsewhere, particularly in DR Congo, Rwanda, Togo, Zambia and Zimbabwe. The culture of other tilapia species is limited and scattered in a few countries.

2.2. Major producers

In 2010, 39 sub-Saharan African countries reported production of farmed tilapia; however, the production of some countries is small (<100 tonnes per year). Ten countries (Côte d'Ivoire, Democratic Republic of the Congo, Ghana, Kenya, Malawi, Nigeria, Sudan, Uganda, Zambia and Zimbabwe) contribute over 95 percent of the total amount of tilapia produced in the African continent, ranging from 87 to 96 percent during 2000 to 2010 (Table 2, Figure 3). However, the major African producer is a non SSA country, Egypt, which produced 86.3 percent of the total African tilapia production in 2010 (FAO, 2012b). The contribution of tilapia to total aquaculture production in the selected ten countries is substantial, ranging from 75 to 100 percent, with the exception of Nigeria and Uganda, where the contribution of tilapia was only 6 and 33 percent, respectively, in 2010 (Table 3). Tilapia production from freshwater environments dominates, representing over 99 percent of total tilapia production in the SSA Region.

Tilapia culture in SSA countries has been growing at an outstanding rate during the past five years, with an overall annual growth rate of 23.46 percent between 2006 and 2010. Moreover, tilapia culture in Uganda, Nigeria, Zambia, Kenya and Ghana is growing at much higher rates than the regional average. In fact, these five countries produced 31 670, 11 989, 10 208, 9 115 and 9 424 tonnes, respectively, representing 82 percent of total tilapia production in SSA countries (35.9, 13.6, 11.6, 10.3 and 10.7 percent, respectively) in 2010.

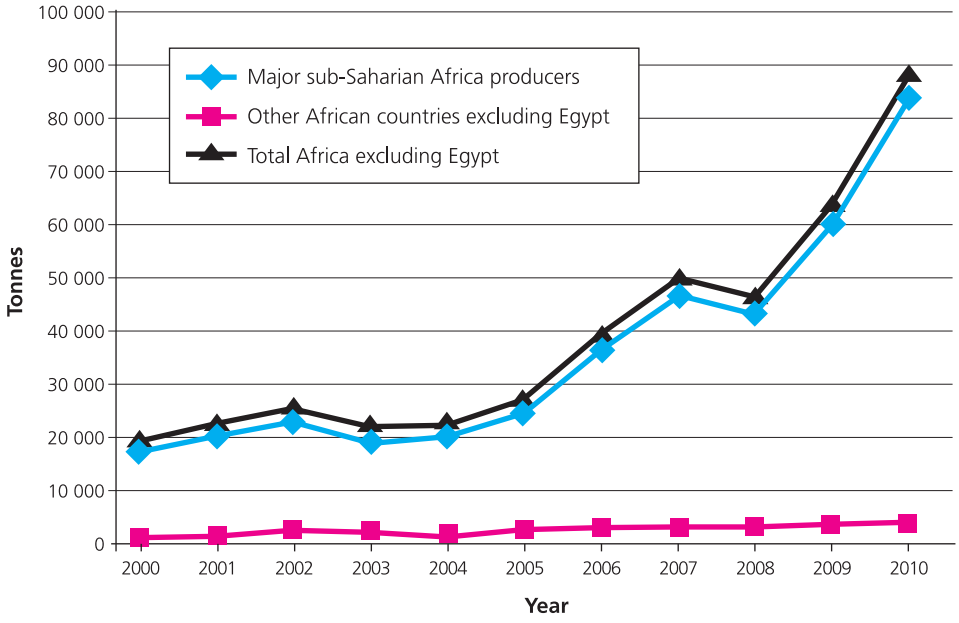
TABLE 1

Tilapia species cultured in sub-Saharan Africa

Species	Côte d'Ivoire	DR Congo	Ghana	Kenya	Malawi	Nigeria	Rwanda	Sudan	Togo	Uganda	Zambia	Zimbabwe
Nile tilapia (*Oreochromis niloticus*)	x	x	x	x		x	x	x	x	x	x	x
Blue tilapia (*O. aureus*)	x											
Mozambique tilapia (*O. mossambicus*)					x							
Three spotted tilapia (*O. andersonii*)											x	
Longfin tilapia (*O. macrochir*)		x					x		x		x	x
Chambo (*O. shiranus shiranus*)					x							
Chambo (*O. karongae*)					x							
Banded jewel fish (*Hemichromis fasciatus*)												
Redbelly tilapia (*Tilapia zillii*)										x		
Redbreast tilapia (*T. rendalli*)		x			x		x				x	x
Guinean tilapia (*T. guineensis*)			x									
Blackchin tilapia (*Sarotherodon melanotheron melanotheron*)	x		x						x			
Mango tilapia (*Sarotherodon galilaeus galilaeus*)			x								x	

Source: El-Sayed (2006); Hecht (2007).

FIGURE 3
Tilapia production by major producing countries in sub-Saharan Africa 2000–2010



Source: FAO (2012b).

TABLE 2
Total tilapia aquaculture production (tonnes) by the ten major producers in sub-Saharan Africa (SSA), 2000–2010 and their contribution to SSA tilapia production

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Côte d'Ivoire	967	870	725	706	706	706	661	1 050	1 050	1 050	1 275
Democratic Republic of the Congo	2 073	2 738	2 959	2 959	2 959	2 959	2 960 D	2 960	2 960	2 960	2 960
Ghana	3 712	4 400	4 400	285	760	954	2 000	3 500	5 100	6 676	9 424
Kenya	222	412	421	600	614	622	609	2 965	3 113	3 424	9 115
Malawi	500	532	620	630	697	767	1 445	1 445	1 656	1 500	2 997
Nigeria	2 705	2 626	4 496	3 948	4 176	6 144	9 216	9 272	3 223	10 218	11 989
Sudan	1 000	1 000	1 000	1 000	1 000	1 000	1 000	1 350	1 350	2 000	2 000
Uganda	600	1 550	1 957	2 200	1 660	4 239	11 388	16 891	17 130	21 573	31 670
Zambia	4 020	4 370	4 530	4 455	5 080	5 080	5 080	5 080	6 504	8 437	10 208
Zimbabwe	2 041	2 165	2 213	2 600	2 950	2 450	2 450	2 450	2 450	2 650	2 700
Total of 10 major producers	17 840	20 663	23 321	19 383	20 602	24 921	36 809	46 963	43 645	60 488	84 338
Total SSA tilapia production	19 526	22 594	26 244	22 224	22 677	27 630	39 883	50 305	46 694	63 776	88 238
% contribution of the ten major producers to SSA total tilapia production	91.4	91.5	88.9	87.2	90.9	90.2	92.3	93.4	93.5	94.8	95.6

Source: FAO (2012b).

TABLE 3
Tilapia production (tonnes) and contribution to total aquaculture production in the ten selected SSA countries in 2010 (tonnes)

Country	Congo, DR	Côte d'Ivoire	Ghana	Kenya	Malawi	Nigeria	Sudan	Uganda	Zambia	Zimbabwe
Tilapia production	2 960	1 275	9 424	9 115	2 997	11 989	2 000	31 670	10 208	2 700
Total aquaculture production	2 970	1 700	10 200	12 154	3 163	200 535	2 200	95 000	10 290	2 702
% of tilapia in total aquaculture production	99.7	75.0	92.4	75.0	94.8	6.0	91.0	33.3	99.2	100.0

Source: FAO (2012b).

2.3 Tilapia culture systems in SSA

Tilapia culture in all SSA countries is categorized by the level of intensity (i.e. extensive, semi-intensive, intensive) with respect to culture systems, species cultured, the intensity of management inputs, labour requirements, feeding and fertilization levels and level of integration with other agricultural/animal production activities.

2.3.1 Non-commercial, extensive culture

Non-commercial, extensive tilapia culture is considered a small-scale, low input-low output activity. It is practiced in earthen ponds, varying in size, depth and ownership. Typically, a farmer owns between one and five ponds with a size range of <100 m² to 1 000 m² (Quagrainie *et al.,* 2005; Hecht, 2007; Chimatiro and Chirwa, 2007). Family labour is generally used, while the use of hired labour is very rare because many small-scale farmers do not have the cash to hire external labour. Pond depth ranges from <50 cm to >1 m.

Monoculture of tilapia (*O. niloticus* and *Tilapia* spp.) is commonly practiced in most of the selected countries. However, polyculture of tilapia with North African catfish (*Clarias gariepinus*) and common carp (*Cyprinus carpio*) is also practiced in Côte d'Ivoire, Malawi, Kenya, Nigeria, Uganda and Zambia. Typically, mixed-sex tilapia is used, although sex-reversed (all male) tilapia culture is becoming widespread in a number of countries (Côte d'Ivoire, Ghana, Kenya, Uganda and Zambia).

Non-commercial, rural/subsistence tilapia culture in SSA countries, especially in Cameroon (Pouomogne, 2007), Kenya (Nyandat, 2007), Malawi (Chimatiro and Chirwa, 2007) and Uganda (Rutaisire, 2007) is primarily based on a fertilization system using a compost crib built inside the pond. The crib varies in size among countries depending on the pond size. In Cameroon, for example, the crib is a bamboo frame occupying about 10 percent of the pond water surface. Prior to stocking the pond, the crib is filled with different inputs that are available on the farm (e.g. weeds, leaves, green fodder, grass, animal manure and household food wastes). The contents are turned and mixed biweekly, the nutrients released from the crib stimulating natural productivity in the pond. In this way, cultured fish (mainly Nile tilapia) depend exclusively on the natural food production of the waterbody.

Stocking densities of tilapia fingerlings in this system are generally low, ranging from 1–4/m². Fingerlings are either collected from the wild or bought from hatcheries (ADiM, 2005; Hecht, 2007). Non-commercial, extensive tilapia culture in SSA is generally integrated with horticulture and/or animal production activities.

2.3.2 Semi-intensive culture

Semi-intensive, small-scale tilapia culture is the most popular farming system in SSA. Both monoculture (mainly Nile tilapia) and polyculture systems are currently in use. More than 95 percent of the farmers in Tanzania culture mixed-sex Nile tilapia in

earthen ponds in monoculture (Quagrainie *et al.,* 2005). Farmers use naturally available feeds, through pond fertilization. However, polyculture systems of *O. niloticus* (or other tilapia species; e.g. *O. shiranus* and *O. mossambicus* in Malawi and *O. andersonii* in Zambia) with *C. gariepinus* or other clariids such as *Heterobranchus* spp. is gaining popularity, particularly in Nigeria, Cameroon, Ghana, Kenya and Uganda, because of the higher yields (Hecht, 2007). Stocking densities in semi-intensive systems generally range from 1 to 4/m². Fishponds are usually stocked using fingerlings left over at harvest or purchased from neighbours (ADiM, 2005).

Pond preparation and management

Semi-intensive tilapia culture is practiced exclusively in earthen ponds. The majority of semi-intensive tilapia farmers in all selected countries pay little attention to pond management practices, in terms of scheduled stocking, fertilization, feeding and harvesting (Hecht, 2007). In Kenya and Tanzania, for example, one person in each household is responsible for managing the fishponds. The management includes pond maintenance, feeding, harvesting and marketing the fish (Quagrainie *et al.,* 2005).

During pond preparation in Malawi, the ponds are dried for two to three weeks or until the soil cracks. Afterwards the ponds are limed to neutralize the soil pH and to eliminate bacteria, parasites and other pathogens. About 3–4 tonnes/ha of cattle manure and 2 tonnes/ha of chicken manure are generally applied. The water is then added and the ponds are left for 7–10 days before the fish are stocked. After a month, if the colour of the water is not yet green, nitrogen : phosphorus : potassium (NPK) fertilizer is applied to boost plankton production. This is done on an annual basis. Pond preparation in Cameroon is performed using quick lime (10 to 30 kg per 100 m² water surface, depending on the nature of the pond bottom and the experience of the farmer (Pouomogne, 2007).

Pond fertilization

In semi-intensive tilapia culture systems in SSA, both organic and inorganic fertilizers are used for pond fertilization. However, the use of fertilizer is constrained by availability, price, transport and cash resources. The majority of non-commercial small farmers use compost and organic fertilizers (animal manure) if available. Meanwhile, small and large-scale commercial farmers use animal manure regularly, and also use chemical fertilizers if necessary. Poultry droppings are the most commonly used manure throughout the SSA Region. Cattle manure is also widely used in some countries. In Malawi, Nigeria, Ghana and Cameroon, chicken manure is most commonly used. On the other hand, about 60 percent of tilapia farmers in Uganda use cattle manure, while chicken manure was least used.

The fertilization rate for organic fertilizers ranges from 2 to 9 tonnes/ha (Table 4). However, it has been reported that actual fertilization rates in some countries are generally lower (<30 percent) than the recommended rates (Hecht, 2007), such as Cameroon (Pouomogne, 2007) and Ghana (Abban, 2005). Generally, tilapia farmers spread dry fertilizer on the pond bottom before filling with water. Other farmers pile the dry manure on farm dikes and spray it with water for few days before washing it into the ponds. This process enhances decomposition and reduces the time needed to achieve maximal primary production in the ponds, compared with dry manure.

TABLE 4

Examples of pond fertilization regimes used in tilapia culture in sub-Saharan Africa

Species (country)	Size (g)	Density (fish/ha)	Fertilization regime	Feeding	Culture period (day)	Yield (tonnes/ha/year)	Remarks	Reference
Oreochromis niloticus (Cameroon)	200–222	7 600	Cattle manure, 226 kg dry wt/ha/day	Cotton seed cake 3% BW*/day, 6% BW/day	100	4.80–6.50	Polyculture with *Clarias gariepinus* (1 100 fish/ha) as police-fish.	Middendorp (1995)
♂ *O. niloticus* (Kenya)	90	1 000	Di-ammonium phosphate (DAP) + urea, 20 kg N/ha/week		133	1.72**	During warm season (23.5–28.2 °C)	Veverica, Bowman and Popma (2001)
♂ *O. niloticus* (Kenya)	16.9	1 000	DAP + urea, 20 kg N/ha/week		147	2.95**	During cool season (22.5–26.4 °C)	Veverica, Boman and Popma (2001)
O. niloticus (Kenya)	45	17 000	DAP and urea (20 kg N/ha and 8 kg P/ha) weekly	Shrimp meal diet at 0, 6 and 12%, 2% BW/day	250	4.10–4.60	Animal protein not necessary in feeds of Nile tilapia raised in fertilized ponds; FCR: 1.3:1	Liti *et al.* (2006a)
T. rendalli (Malawi)	18	20 000	Chicken manure (500 kg/ha/week), pig manure (500 kg/ha/week), cattle manure (1 200 kg/ha/week)		84	0.58–1.26	Chicken manure was best	Kang'ombe, Brown and Halfyard (2006)
T. rendalli (Malawi)			3–4 tonnes of cattle manure and 2 tonnes of chicken manure per ha, NPK fertilizer is applied when needed	Farm-made feed, hand fed, once or twice daily		8.9		Longwe, Kang'ombe and Kaunda (2010)
♂ *O. niloticus* (Kenya)	21	20 000	Urea (20 kg N/ha) and DAP (8 kg P/ha) weekly	Wheat bran, local diets, pig diets; twice per day, 2% BW/day	258	6.20–7.70	*C. gariepinus* (1 000 fish ha) used as police-fish; formulated feed was best; wheat bran was most economic; FCR: 2.6:1–3.0:1	Liti *et al.* (2005)
O. niloticus (Kenya)	14	19 462	Urea (20 kg N/ha) and DAP (8 kg P/ha) weekly	Rice bran, wheat bran, maize bran	250	1.29–2.04**	*C. gariepinus* (250 fish/ha) stocked; maize bran produced highest yield; wheat bran was most cost-effective	Liti *et al.* (2006b)

*BW = body weight;

**Production (tonnes) per culture period provided.

Source: see reference column.

In Malawi, tilapia ponds are fertilized during preparation, and afterwards at monthly intervals. Fishponds are fertilized with composted manure or with poultry, goat and/or cattle manure. Tilapia are also fed with on-farm agricultural by-products, such as maize or rice bran, if available (Chimatiro and Chirwa, 2007).

Animal manure (pig, chicken and duck) is also widely used in Kenya in tilapia production in earthen ponds. The quality of manure as a fertilizer varies depending on the source animal and the quality of feed fed to the animal. Application rates depend on the size of the pond, stocking density and water productivity. Generally, a fertilization rate of 5 kg/100 m²/week is used. Manure is applied using the following methods:

- Crib method, where a compost crib is constructed using wooden sticks at one or more sides of the pond. The manure in the crib is frequently mixed to facilitate the gradual release of nutrients into the pond.
- Bag method, where a bag is filled with manure and tied to the corner of the pond. The bag is shaken weekly or daily to release nutrients.

In Cameroon, small-scale commercial tilapia farmers use single feed ingredients to feed their fish along with pond fertilization. This practice is often integrated with domestic animal production (mainly chickens or pigs). Normal stocking density is 1 to 2 tilapias plus 1 catfish per m², plus some other fish species at a lower density. Higher production levels have been recorded when the number of species in the pond is increased and feeding and pond fertilization are adequate.

Supplemental feeding

Tilapia farmers in the selected countries use a variety of feed inputs, depending on fish size, stocking density, water productivity and culture system. The inputs range from single feed ingredients such as maize bran, corn bran, wheat bran and rice bran to farm-made feeds. They also used kitchen leftovers and leaves. Feeding regimes also vary from one country to another. In Malawi, for example, *T. rendalli* and *O. shiranus* are fed by the broadcasting method, where the feed is sprinkled into the ponds by hand. Feed is offered once or twice daily, depending on the production stage. Fingerlings are fed twice daily (around 07.00 and between 12.00 and 13.00), while fish in fattening ponds are fed only once a day.

The production levels in semi-intensive pond systems vary considerably from one country to another, depending on tilapia species, stocking size and sex, culture inputs, farming system and duration of the production cycle. Therefore, production ranges from less than one tonne/ha/year to over 7 tonnes/ha/year (Table 4). Polyculture of Nile tilapia and North African catfish is commonly practiced throughout the region.

Commercial tilapia culture in earthen ponds

Commercial aquaculture in earthen ponds is well developed in Nigeria and Zambia. In many of the selected countries, polyculture of *O. niloticus* and *C. gariepinus* is currently the most popular practice, although some farmers use other combinations. While polyculture is practiced in all countries, commercial farmers in several countries also produce *O. niloticus* (Zambia and Kenya) and *C. gariepinus* (Nigeria) under monoculture farming conditions. Production levels range from 2.5 to 15 tonnes/ha/year for *O. niloticus* (monoculture) and *O. niloticus*/*C. gariepinus* polyculture, and up to 10–30 tonnes/ha/year for *C. gariepinus* monoculture in Nigeria (Hecht, 2007). The size of the production ponds ranges from 500 m² to 1.5 ha. Stocking densities in earthen ponds average around 5–8 fingerlings/m².

The majority of tilapia farmers feed their fish manually with farm-made feeds or commercial pellets. However, automated feeding systems (Figure 4) are being investigated in Zimbabwe to deal with the expected growth and high tilapia biomass anticipated in the coming years (Pasipamire, 2009).

FIGURE 4
Feeding tilapia ponds in Zimbabwe using mechanical blower

COURTESY OF W. PASIPAMIRE.

Tilapia-rice farming

The potential of tilapia culture in rice fields has been investigated (Kabré, 2000; Miller, 2006; Sanni and Juanich, 2006) and appears very high, especially in Mali, Burkina Faso, Senegal, Côte d'Ivoire and Ghana. Oswald, Copin and Monteferrer (1996) reported positive interactions and returns from the farming of Nile tilapia in ponds adjacent to lowland rice fields in peri-urban zones of Côte d'Ivoire. The activity was a suitable farm diversification strategy and benefited from the proximity of markets.

Farming Nile tilapia in rice fields in an integrated system has also been tried in Ghana (Ofori *et al.,* 2005). Fingerlings (25 g average weight) were stocked at 3 000 per hectare in rice fields (refuge pits) 15 days after transplanting. Some of the refuge pits were manured with poultry droppings at 30 kg/ha, whereas supplementary feeding with rice bran was applied to the ponds at a rate of 5 kg/ha/week. The fish were harvested ten days after the rice was harvested. The results indicated that the presence of the fish did not significantly reduce the rice harvest. The percentage increase in revenue from the rice-fish system over rice monoculture ranged from 5 to 11 percent. These results suggest that rice-fish integration could be a viable option for diversification for smallholder rice farmers in lowlands with soil and water conservation structures and a reliable source of water for irrigation.

2.4 Intensive culture

Intensive tilapia culture is practiced in a few SSA countries (Ghana, Kenya, Nigeria, Malawi, Zambia, Zimbabwe and Uganda), mainly in cages and earthen ponds and, to a lesser extent, in tanks and raceways.

2.4.1 Cage culture

In SSA, the contribution of tilapia production from cages is relatively low and varies between countries (Jamu, 2001, El-Sayed, 2006). Nile tilapia and chambo (*O. shiranus* and *O.karongae*) are the main species cultured (Blow and Leonard, 2007). Cage culture is currently practiced in Ghana, Kenya, Malawi, Uganda, Zambia and Zimbabwe. Small cages (6 x 6 x 3 m) constructed from locally available materials are generally used in many of the ten selected countries. In addition, commercial, medium- to large-scale cages (800–1 200 m^3) are used in Ghana (Hecht, 2007). Cage culture of tilapia in Africa, especially for small-scale farmers, is affected by the availability and cost of seed and feed, unpredictable water sources and water quality. Table 5 summarizes the cage culture of tilapia in SSA.

TABLE 5

Tilapia cage culture in the sub-Saharan Africa region

Country	Cage size and shape	Tilapia species	Stocking density	Initial size (g)	Feed and feeding	Period (month)	FCR	Harvest size (g)
Ghana (Crystal Lake)[1]	Circular, 32 m dia, 5 m depth	*Oreochromis niloticus*	100 000 fish/cage (0.5–1.0 kg/m^3)	5–8	Powdered feed	2		40–50
Ghana (Crystal Lake)[1]	Circular, 32 m dia, 5 m depth	*O. niloticus*	50 000–60 000	40–50	Extruded, sinking pellets	3	1.7:1–2.2:1	250
Ghana (Volta Lake)[2]	6×4 m on the sides, 2 m deep (48 m^3)	*O. niloticus* all-male and mixed sex	63–188 fish/m^3	10–30	Imported floating pellets (28–32% CP), manual feeding, 2–3 times/day	6	1.4:1–2.5:1	250 (mixed sex) 400 (all-male)
Kenya (Harambee Dam, Nyanza)[3]	Rectangular, 0.64 m^3	All-male tilapias	130	20	30% CP, farm-made, semi-floating, 6% BW/day	7		285
Uganda (Lake Victoria)[4]	2x2x2 m		2 400	15–18	On-site, sinking feed, demand feeders	12		700
Ethiopia (Lake Kuriftu)[5]	1x1x1 m	*O. niloticus*	50	46	Mill sweeping, cotton seed, and Bora* food complex at 2% BW/day, feeding trays	5	2.48:1	220
Zimbabwe (Lake Kariba)[6]	Cylindrical, 1 000 m^3, 17 m diameter	*O. niloticus*			Pellets (sinking and floating) and crumb-based feeds, 30–45% CP, 1.7-3.0% BW/day	7		690
Malawi (Maldeco Ltd, Lake Malawi)[7]		*O. shiranus*	65–75/m^3	30	Local, low quality	6–9		20–40 kg/m^3
Kenya (Dominion Farms Ltd)[7]	Square (4 m^3)	*O. niloticus*			Imported pellets			200 kg/m^3

Notes: CP = crude protein, BW = body weight; FCR = feed conversion ratio

*Bora is a local feed plant, produce cattle feed from nut cake, wheat bran and corn bran

Source: [1]Blow and Leonard (2007); [2]Ofori *et al*. (2009); [3]Charo-Karisa (2009); [4]Gatward (2009); [5]Gibtan, Getahun and Mengistou (2008); [6]Pasipamire (2009); [7]Hecht (2007).

The largest and most successful commercial farm for cage culture of tilapia (Lake Harvest) is located on Lake Kariba, Zimbabwe (Figure 5). The farm includes 14 cylindrical cages, each cage (bag-net) having a volume of 1 000 m^3 and a diameter of 17 m. The total production of the farm is about 3 000 tonnes/year. The facility is also provided with a very high-standard processing unit. The tilapia produced are exported, either as fresh fillets or frozen, to Europe and the United States of America (Windmar, Jarding and Paterson, 2000; El-Sayed, 2006). The fish are fed with commercial extruded pellets made in Zimbabwe for Lake Harvest.

FIGURE 5
Feeding tilapia in cages in Lake Kariba, Zimbabwe

COURTESY OF W. PASIPAMIRE.

A similar cage farm consisting of 32 cages has been established in Lake Malawi (Malawi), with a target production of 3 000 tonnes of chambo (*O. karongae* or *O. shiranus*). Initial stocking density ranges from 65 to 75 fingerlings per m^3 (30 g average weight). After a rearing cycle of about six to nine months, final harvest ranges from 20 to 40 kg/m^3.

Cage-cultured tilapia are generally fed with farm-made, sinking feed. Feed is dispensed by hand two to three times a day (morning, midday and/or late afternoon). The feeding regime is planned and quantities measured in advance to make sure that fish have optimum growth and the best possible FCR. However, the large-scale tilapia cage farm in Lake Kariba, Zimbabwe feed the fish 30 to 45 percent crude protein (depending on developmental stage) sinking and floating pellets and crumbles (Pasipamire, 2009). The FCR of cage-cultured tilapia ranges from 1.4:1–2.5:1, depending on fish size, stocking density, and feed type and quality

Although floating feeds are preferred, they are expensive to produce and not yet available on a commercial scale in Uganda. However, a number of companies have started producing floating/extruded pellets on a relatively small scale. In addition, imported feeds have been tried at some locations in Uganda, but they are expensive and thus not economically viable for large-scale commercial farms.

2.4.2 Tank and raceway culture

Tilapia culture in concrete tanks and raceways is very limited and is practiced in only a few countries. In Kenya and Zambia, circular and 'D-ended' concrete tanks are used for the production of Nile tilapia (Hecht, 2007). The size and shape of tilapia culture tanks vary depending on the culture objectives. Fry and nursery tanks are generally small (<2 to 10 m^3) (Figure 6), while production tanks are much larger. Fish are fed farm-made pellets or commercial feeds twice a day (morning and afternoon); younger fish are fed more frequently. Tilapia ponds are often aerated with paddle wheels or blowers, where appropriate.

FIGURE 6
Concrete tanks for nursing Nile tilapia, Lake Harvest, Zimbabwe

COURTESY OF R. BRUMMETT.

3. ON-FARM TILAPIA FEED MANUFACTURING

The vast majority of non-commercial/semi-intensive tilapia farms in SSA rely on farm-made feeds. In Nigeria, for example, about 70 percent of the tilapia feeds used is farm-made (dry mash, dough balls and meat-mincer pellets, fed in moist or sun-dried form) (Ayinla, 2007). This is mainly because small-scale commercial farmers cannot afford manufactured pelleted feeds. About 100 000 tonnes of farm-made feeds are currently produced annually in the region (Hecht, 2007). On the other hand, about 20–30 percent of commercial fish production is attributed to industrial aquafeeds. The main protein sources of farm-made feeds are oilseed cakes (cotton, soybean and sunflower), fishmeal, blood meal, carcass meal, brewer's waste, groundnut cake, palm kernel cake, and poultry by-product meal. Energy sources include cereal bran, corn, kitchen waste and vegetables. Farm-made feed formulations vary by country and season, depending on availability and price of ingredients and the culture system adopted. These formulations range from single feed ingredients, such as wheat bran, rice bran or ground corn, to formulated mixes, moist feed cakes and processed, dry pellets. Farm-made feed production depends mainly on trial and error and is based on limited scientific knowledge. Therefore, further nutritional research is urgently needed in the SSA Region. Typically, local feed formulation includes the following steps:

- sourcing of ingredients (mainly locally available);
- grinding (using a hammer mill) (Figure 7);
- mixing (manually in most cases, using a shovel, to ensure proper blending);
- pelleting, using locally produced pelleting machines operated by diesel engine, electricity (Figure 8) or manually;
- drying (mostly sun-drying, occasionally oven-drying or the use of a kiln); and
- storing (on farm dykes or in stores).

These feeds are made using easy and simple techniques. The feedstuffs are milled and mixed at predetermined ratios. Mixing is done by hand or with the use of mechanical mixers. Some of the ingredients, such as soybean meal and maize meal, are precooked to get rid of the antinutrients they may contain (i.e. protease inhibitors, gossypol and haemagglutinin) and to improve the binding capacity and digestibility of the feed. Warm water is gradually added to the mixture, with continuous mixing until a firm dough is obtained. Moist strands are extruded using a hand or electrically operated meat mincer or pasta maker (Figure 8). The strands are sun-dried or oven-dried, broken up into appropriate sizes, and stored.

FIGURE 7
Ingredient grinder in Ghana

COURTESY OF N. AGBO.

FIGURE 8
Making on-farm aquafeed in Nigeria

COURTESY OF K. JAUNCEY.

Farm-made feeds in SSA are generally characterized by their poor quality, high price and inconsistent production rate. These feeds also have common problems throughout the region. Many small-scale farmers do not add micronutrients such as vitamin and mineral mixes and antioxidants to diet formulations. This practice leads to considerable reduction in storage time and the acceleration of spoilage. Another major problem associated with farm-made feeds is the high content of fines, which leads to feed wastage and poor FCR. It is no surprise, therefore, that the FCR of locally produced tilapia feeds ranges from 0.95:1 to >6:1 (Liti *et al.*, 2005; Hecht, 2007; Pouomogne, 2007; Rutaisire, 2007; Nyandat, 2007; Chimatiro and Chirwa 2007). The formulation and protein content of tilapia feeds (both farm-made and industrial feeds) in different countries of the SSA region are summarized in Table 6.

TABLE 6

Formulation (percent) and protein content (see notes) of farm-made and industrial tilapia feeds in various countries of the sub-Saharan Africa Region

Ingredient	Grower[1]	Grower[2]	Grower[3]	Grower[4]	Industrial[5]	Industrial[6]	Starter/ broodstock[7]	Industrial[8]	Fingerling[9]	Grower[9]	Finisher[9]
Fishmeal		20		15	16	11	30	15	32.69	32.69	24.4
Blood meal						13.5	5				
Carcass meal							15				
Bone meal	1										
Shrimp meal											
Soybean meal				45			15	45			
Soybean cake	13	15				3					
Cotton seed cake	15	15			17	4			10	10	10
Groundnut cake	12	5									
Sunflower cake			30								
Copra cake					17						
Brewery waste	10	15									
Rice/wheat bran	20	15				8			18		
Wheat bran					50				35	35	35
Rice bran										18	18
Wheat flour							22				
Maize bran			50			7	10.5				
Cocoa husk	10										
Layer droppings meal	15										
Pigeon pea meal			20								
Cassava flour						4					
Maize		8		25		49		25	2.8	2.8	2.8
Maize germ											
Palm oil	2	2									
Vegetable oil				6				6			
Fish oil				4				4			
Starch/binder				2				2			
Vitamin and mineral premix	2	5		3		0.5	2.5	3	0.5	0.5	0.5
Shell									0.39	0.38	1.71
Salt									0.23	0.23	0.47
DL-Methionine									0.04	0.04	0.02
L-Lysine									0.35	0.35	0.10

[1] 31% crude protein (CP), for semi-intensive Nile tilapia in fertilized ponds (Cameroon) (Hecht, 2007); [2] 35% CP, for Nile tilapia in fertilized ponds (Cameroon) (Hecht, 2007); [3] 20% CP, for common carp and Mozambique tilapia in fertilized ponds (Malawi) (Hecht, 2007); [4] 38% CP, for Nile tilapia (Nigeria) (Hecht, 2007); [5] 25% CP, industrial tilapia feed (Kenya) (Nyandat, 2007); [6] Industrial pellets for Nile tilapia and North African catfish in polyculture (Cameroon) (Hecht, 2007); [7] 37% CP, for catfish, carp and tilapia fingerlings and broodstock (Malawi) (Chimatiro and Chirwa, 2007); [8] 30% CP, tilapia feed (Nigeria) (Ayinla, 2007); [9] Moehl and Halwart (2005), (Côte d'Ivoire): fingerlings (1–30 g, 32% CP); grower (30–100 g; 32% CP); and finisher (100–500 g, 28% CP).

Tilapia feeding practices also vary widely. Non-commercial farmers feed their fish at irregular intervals, depending on the availability of resources and by-products. Feeding practices also vary by country depending on the level of extension and knowledge of the farmer (Nyandat, 2007). Cereal bran is broadcast over the water surface by hand, while kitchen and fruit wastes, vegetables, grass and maize stovers are placed into the pond cribs. Supplemental feeding is provided mainly by hand, two to three times per day, whereas demand feeders are rarely used.

Small and large-scale commercial tilapia farmers in Malawi apply the feed in the form of a moist mash in feeding bags or on trays, or in pelleted form (Chimatiro and Chirwa, 2007). The fish are fed on a regular basis once or twice per day depending on average fish size and pond management. Fish in fattening ponds are fed daily, while those in fingerling ponds are fed twice daily (0700 and 1200 to 1300 hours). *Tilapia rendalli* and *Oreochromis shiranus* are fed by the broadcasting method, where the feed is sprinkled into the ponds by hand (Chimatiro and Chirwa, 2007).

4. THE COMMERCIAL AQUAFEED INDUSTRY

The commercial aquafeed industry in the SSA Region is relatively new and is still in the developmental phase. This industry is one of the least developed subsectors of aquaculture in the region (Hecht, 2007). Feed remains one of the major barriers facing the expansion of tilapia culture, especially for medium- and large-scale producers. SSA relies heavily on imported feed ingredients and commercial fish feeds, which makes fish farming expensive, as fish feed accounts for at least 60 percent of the total cost of production. Therefore, only a few countries in the region produce formulated, commercial aquafeeds (i.e. Nigeria, Cameroon, Ghana, Kenya, Malawi, Uganda (Figure 9), Zambia and Zimbabwe) (Hecht, 2007; Gabriel *et al.*, 2007). However, commercial feed production in these countries is limited, and the number of commercial aquafeed mills is low. This has been attributed mainly to the following reasons:

- the demand for commercial fish feed is too low to justify industrial scale production; and
- high production and transportation costs (the cost of commercial tilapia feeds (20–25 percent crude protein) ranges from US$225 to >US$600/tonne, depending on the country, feed source and composition).

FIGURE 9
Storing and selling commercial fish feed in Uganda

Source: www.sarnissa.org/tiki-browse_gallery.php?galleryId=7

In SSA, where aquafeed is commercially produced there are problems related to consistency of supply and quality. As with farm-made aquafeeds, commercially produced aquafeeds contain substantial amounts of fines (up to 50 percent; Hecht, 2007). Quality control over aquafeed mills is almost absent in most countries of the region. Thus, fish farmers in general and tilapia farmers in particular are forced to rely on farm-made feeds and, to a lesser extent, on imported pelleted feeds. As a result, as stated earlier, the majority of tilapia farmers in SSA make their own feeds on-farm.

5, MAJOR FEED INGREDIENTS

The major feed ingredients that can be used in tilapia feed production are generally available across the SSA Region. However, the status of the existing livestock feed manufacturing capacity, the availability of quality feed ingredients, the availability and accessibility of suitably trained personnel and the presence of favourable legislative and taxation systems are the main indicators of the ability of each country to produce aquafeeds. The increasing competition for feed ingredients among the animal and aquaculture production sectors is expected to increase the prices of feed ingredients and processed aquafeeds. In fact, their prices have already sharply increased over the past few years.

The reported quantities of major feed ingredients produced in SSA that are available for feeding fish and/or manufacturing fish feeds are given in Table 7. Varying quantities of protein sources, especially oilseed sources (i.e. groundnut, soybean, cottonseed, sunflower and sesame seed) are produced in the ten major tilapia farming countries. Similarly, substantial amounts of energy sources, including maize, maize bran, wheat bran, sorghum and millet are produced. Varying amounts of vegetable oils are also produced. This means that the potential of the aquafeed industries in these countries is high. However, the cost of feed ingredients, such as fishmeal and oilseed meals/cakes is a major constraint to the development of aquafeed industries in most places. The price of feed ingredients, particularly fishmeal, oilseed cakes, soybean meal and maize varies highly among countries and seasonally within countries.

The imports and exports of major food/feed commodities in SSA in 2010 are given in Tables 8 and 9. These tables indicate that a short list of varying amounts of plant protein, oil and energy sources are imported to SSA, whereas a longer list of feed ingredients are exported. The prices of these ingredients also vary significantly among the countries of the region and even within the same country, depending on the amounts produced, the quality and the season. For example, the price of imported maize in 2010 ranged from US$329/tonne in Zimbabwe to US$669/tonne in Malawi (Table 8). Similarly, the price of soybean ranged from US$305 (Kenya) to US$1 006 (Malawi). Soybean oil prices fluctuated between US$1 197/tonne (Zambia) and US$2 350/tonne (Malawi).

Countries that have expanding and developing agricultural sectors with surplus production, such as Ghana, Kenya, Malawi, Nigeria, Uganda, Zambia and Zimbabwe, are well placed for the economical production of commercial fish feed. These countries produce surplus amounts of the major feed ingredients and even export varying quantities of these ingredients (Table 9). Kenya, Uganda and Zimbabwe export large amounts of protein (oil seeds and oil seed cakes) and energy (maize and sorghum) sources. In Uganda, for example, soybean cake is exported at US$59/tonne, whereas in Zambia it is exported at US$439/tonne (Table 9). Maize is exported from Uganda at US$214/tonne but at US$1 346/tonne from Ghana. Export prices of wheat bran also ranged from US$37/tonne (Kenya) to US$171/tonne (Sudan).

TABLE 7

Production (tonnes) of major agricultural commodities in the selected sub-Saharan Africa countries in 2010

Commodity	Congo, DR	Côte d'Ivoire	Ghana	Kenya	Malawi	Nigeria	Sudan	Uganda	Zambia	Zimbabwe
Maize	1 156 410	641 610	1 871 700	3 464 540	3 419 410	7 676 850		2 373 500	2 795 480	1 192 400
Rice	317 231	722 609	491 603		110 106	4 472 520		218 111	51 656	
Sorghum			324 422	164 066	53 932	7 140 970	2 630 000	390 779		73 675
Cassava	15 049 500	2 306 840	13 504 100	323 389	4 000 990	42 533 200		5 282 000	1 151 700	204 236
Dry bean				390 598	153 815			455 000		
Vegetable, misc.	370 000			692 461	182 168	5 945 600	525 000	760 000	310 179	157 552
Wheat				511 994			403 000		172 256	50 100
Cocoa bean		1 242 290	632 037							
Coffee, green		94 321						166 968		
Sugar cane	1 950 000	1 650 000	145 000	5 709 590	2 500 000	1 401 680	6 728 000	2 400 000	3 500 000	3 100 000
Millet			218 952			5 170 430	471 000	903 000	47 997	
Groundnut with shell	371 263	90 227	530 887		297 487	3 799 240	762 500	172 000	163 733	106 147
Soybean					73 356			175 000	41 000	57 328
Cottonseed					19 000	228 000	71 000		70 500	69 000
Sunflower seed								230 000		
Sesame seed							350 000	170 000		
Palm oil	187 000	330 000	120 000			1 350 000				
Cottonseed oil	1 836	9 516			4 163	8 800	4 200	5 000	5 833	19 100
Groundnut oil	17 619	2 320	72 168		21 600	850 000	27 032	5 600	3 600	8 700
Palm kernel oil		33 600	16 000			451 177				
Maize oil				13 950						15 300
Sunflower oil							60 083	78 700		3 800
Sesame oil						2 400	63 900	27 700		
Soybean oil						3 600		25 200	3 600	12 500

Source: FAO (2012a).

TABLE 8

Imports of major food/feed commodities in the ten selected sub-Saharan Africa countries in 2010 (quantity in tonnes and price in US$/tonne)

Ingredient	Congo, DR		Côte d'Ivoire		Ghana		Kenya		Malawi		Nigeria		Sudan		Uganda		Zambia		Zimbabwe	
	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price
Wheat	398 751	246	523 461	261	315 838	371	844 559	261	176 822	685	3 971 861	263	1 843 941	259	371 304	348			335 480	503
Milled rice	47 480	374	837 920	548	320 143	629	282 315	356			1 885 334	438	19 085	688	77 202	387	11 444	484		
Maize			16 636	354			229 596	301	15 395	669			103 921	243			5 704	436	173 824	329
Sorghum													437 117	218					30 065	463
Soybean							15 778	305	18 68	1 006									20 818	459
Dry bean					40 284	291	26 096	586					69 122	626						
Rapeseed oil	7 000	7 000																		
Soybean oil									14 167	2 350							7 459	1 197	21 937	1 360
Vegetable oil	22 500	1 218			32 292	543														
Palm oil	78 000	1 205	74 449	988	134 600	1 150	53 6572	844	5 343	1 936	780 000	1 282	62 100	900	203 096	872	60 104	906		
Sunflower oil									3 031	1 688			51 600	872					70 614	1 362
Soybean cake			15 916	502																
Sunflower cake							64 167	33												
Cottonseed cake							39 948	93											30 338	272

Source: FAO (2012a).

TABLE 9

Export of major food/feed commodities from the ten selected sub-Saharan Africa countries in 2010 (quantity in tonnes and price in US$/tonne)

Ingredient	Congo, DR		Côte d'Ivoire		Ghana		Kenya		Malawi		Nigeria		Sudan		Uganda		Zambia		Zimbabwe	
	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price	Quantity	Price
Sorghum							49 709	178					5 001	440						
Maize					8 720	1 346			7 841	648					127 314	214	59 584	590		
Maize flour									1 845	529					57 221	127				
Maize bran																	33 369	125		
Wheat	430	233							7 337	90			600	460			3 016	393		
Wheat bran	29 030	149	81 668	93			26 822	37	6 990	94	127 597	147	5 952	171	24 198	84	4 545	64		
Wheat flour			63 447	383					6 681	453					14 440	229	43 705	619		
Milled rice															40 009	411				
Dry bean									7 254	924					18 773	388				
Cocoa paste			147 371	4 062																
Cocoa powder/cake			30 420	3 709							8 098	2 775								
Cocoa bean	1 167	2 255	790 912	3 135	281 437	3 011					226 634	2 912			16 850	2084				
Banana	887	53	335 593	404	11 030	246							3 264	503					3 244	139
Dry pea							20 559	639	20 475	968										
Molasses													6 000	165	14 105	34	42 497	42	28 940	65
Vegetables (fresh/dried)	239	2 669					42 435	3 543			7 488	1 446	6 635	1 162						
Cassava, dried															11 397	58				
Soybean									10 671	656	11 000	345					14 445	413		
Soybean cake															62 104	59	15 066	439		
Sesame seed					7 406	444					140 800	987	138 000	1 319	12 071	1 065				
Sunflower seed									6 681	547										
Sunflower cake															20 223	33				
Cottonseed			36 132	189					7 256	141	8 600	366					32 603	162	12 844	252
Cottonseed cake																	14 968	184	30 296	271
Palm kernel cake											65 500	153								
Palm oil	500	350	201 172	750	55 000	836	69 790	1 198			13 000	923			19 755	853				
Palm kernel oil	800	1 500									3 000	1 000								
Vegetable oil					5292	1 336														
Sunflower oil													6 000	2 300						

Source: FAO (2012a).

The composition of feed ingredients that can be used for tilapia feed formulation in some SSA countries is given in Table 10. The nutrient contents of these feedstuffs vary significantly from one country to another, depending on their quality, processing and storage. For example, the protein content of sunflower cake ranges from 26 percent (Kenya) to 42 percent (Uganda). Similarly, the lipid and ash contents of sunflower cake range from 4.4 to 14.3 percent and from 5.1 to 32.6 percent, respectively.

TABLE 10

Proximate composition of selected feedstuffs for production of Nile tilapia (*Oreochromis niloticus*) in selected sub-Saharan African countries

Product	DM	CP	CL	CF	NFE	Ash
Animal sources						
Freshwater shrimp meal[1]	87.7	63.5	1.3	5.0	6.7	22.8
Fishmeal[2]	87.0	47.3	21.9	0.8	0.1	26.9
Meat and bone meal[2]	98.7	55.6	25.3	0.1	-	14.7
Blood meal[3]	87.6	60.5	2.3	0.0	11.7	25.5
Hydrolysed feather meal[1]	89.1	79.7	2.4	4.8	9.6	3.5
Hydrolysed feather meal[1]	89.7	80.8	1.9	3.1	4.3	10.0
Omena (*Rastrineobola argentea*)[1]	87.9	55.1	18.7	1.3	6.8	18.2
Seed meals						
Cottonseed cake[1]	89.3	38.8	10.7	24.9	19.2	6.3
Cottonseed cake[1]	90.2	39.3	8.1	48.5	21.7	30.1
Cottonseed cake[3]	94.0	41.1	6.2	6.2	38.0	7.9
Soybean cake[3]	87.0	43.0	1.8	6.5	-	-
Papaya seed meal[1]	94.5	26.4	31.6	11.9	20.3	9.8
Sesame cake[3]	89.5	38.5	9.0	4.0	-	-
Sunflower seed cake[1]	92.9	25.9	5.4	36.8	26.6	5.1
Sunflower cake[3]	91.0	34.1	14.3	6.6	13.2	31.8
Sunflower cake[1]	93.1	25.9	4.4	4.4	34.5	32.6
Sunflower oil cake[3]	94.8	41.7	12.9	16.5	30.8	4.6
Soybean[2]	94.2	52.9	1.4	4.0	35.0	6.7
Sunflower cake[2]	98.5	25.3	15.3	22.9	31.2	5.3
Cereals						
Maize[4]	90.2	13.2	11.4	4.8	65.4	5.2
Cassava[3]	88.0	2.5	-	4.5	-	-
Millet[5]	91.3	4.8	1.3	38.3	41.2	5.7
Sorghum[5]	88.0	7.8	4.8	7.6	65.7	2.1
Cereal brans						
Maize bran[1]	89.4	11.8	10.7	5.5	69.1	2.9
Maize bran[6]	89.0	11.6	4.4	12.3	57.7	3.0
Maize bran[2]	92.0	10.1	9.6	14.7	54.5	11.0
Rice bran[1]	92.3	7.0	4.1	30.9	34.9	22.9
Rice bran[6]	92.1	6.4	6.9	42.3	15.1	22.0
Wheat bran[1]	88.2	17.1	5.8	12.7	58.2	6.0
Wheat bran[6]	88.3	14.3	6.5	31.5	19.0	13.8
Wheat bran[2]	87.7	13.8	10.8	9.1	52.9	1.1
Groundnut bran[7]	94.0	21.7	9.0	17.5	47.0	4.8
Plant parts						
Arrowroot leaves[1]	90.3	33.5	8.5	10.6	38.1	9.3
Banana peel[1]	90.1	7.2	7.9	11.3	62.7	10.9
Banana stem[1]	92.6	10.0	5.0	44.1	20.5	20.5
Banana leaves[1]	89.9	17.0	12.7	24.1	33.7	12.4
Boiled tea leaves residue[1]	91.9	27.9	14.9	14.8	37.7	4.7
Cassava leaves[1]	91.9	30.8	8.6	15.6	36.8	8.2
Leucaena leaves[1]	92.9	28.0	7.1	15.8	39.1	9.9
Mango seed embryo[1]	90.7	7.0	9.7	3.7	77.1	2.4
Papaya peel[1]	83.9	17.9	1.8	19.4	45.6	15.4
Papaya leaves[1]	90.3	28.2	10.5	13.0	32.9	15.4
Pyrethrum, whole[1]	89.0	15.0	4.5	28.2	42.0	10.4
Sweet potato leaves[1]	89.2	35.3	4.3	10.5	38.8	10.4
Water fern, whole[1]	88.8	23.2	4.9	30.2	23.9	17.9
Water hyacinth, whole[1]	89.5	13.3	1.8	26.0	40.7	18.8

Notes: DM = dry matter, CP = crude protein, CL = crude lipid, CF = crude fibre, NFE = nitrogen free extract; Some of the columns showing these analyses do not add to 100%; however, these were the data reported in the cited papers
Source: [1] Munguti *et al.* (2006) (Kenya); [2] Chimatiro and Chirwa (2007) (Malawi); [3] Rutaisire (2007) (Uganda); [4] Nalwanga *et al.* (2009) (East African countries); [5] Ayinla (2007) (Nigeria); [6] Liti *et al.* (2006b) (Kenya); [7] Abban (2005) (Ghana).

As exemplified in Table 10, substantial amounts of information are available on the proximate composition of conventional and unconventional feed ingredients that are locally available in SSA and have potential as fish-feed inputs. Several studies have been carried out on the optimal inclusion levels of these ingredients in tilapia feeds (El-Sayed, 1999, 2006; El-Sayed and Tacon, 1997). However, in SSA countries limited information is available on the replacement of expensive protein sources, especially fishmeal, with locally available animal and plant protein sources. Only a few studies have been carried out in this regard, most of them in Nigeria (Table 11). On the other hand, local protein sources (mainly oil seed cakes) and energy sources are widely used for tilapia feed formulation (Table 6), but mostly without scientific basis.

TABLE 11
Inclusion levels of different feed ingredients in tilapia feeds in the sub-Saharan Africa region

Feed source (country)	Levels tested (%)	Requirement (%)	Species (weight, g)	References
Shrimp head waste (Nigeria)	0–60	60	*Oreochromis niloticus* (1.4)	Nwanna and Daramola (2000)
Fish silage + soybean meal or meat and bone meal (Nigeria)	0–75	50–75	*O. niloticus* (8)	Fagbenro (1994)
Poultry by-product meal or hydrolysed feather meal (1:1) (Nigeria)	0–75	50–75	*O. niloticus* (8)	Fagbenro, Jauncey and Haylor (1994)
Jackbean meal (cooked in distilled water) (Nigeria)	20–30	20	*O. niloticus* (7.6)	Fagbenro, Adeparusi and Jimoh (2004)
Jackbean meal (cooked in trona[1] solution) (Nigeria)	20–30	30	*O. niloticus* (7.6)	Fagbenro, Adeparusi and Jimoh (2004)
Defatted cocoa cake (Nigeria)	100	100	*Tilapia guineensis* (52)	Fagbenro (1988)
Macadamia press cake (Nigeria)	0–100	50	*O. niloticus* (7.5–12)	Balogun and Fagbenro (1995)
Macadamia press cake (Nigeria)	100	100	*T. guineensis* (NA[2])	Fagbenro (1993)
Cottonseed meal (Kenya)	0–100	100	*O. niloticus* (45), in fertilized ponds	Liti *et al.* (2006a)

[1] Trona (sodium sesquicarbonate/trisodium hydrogendicarbonate dihydrate, $Na_3(CO_3).(HCO_3).2H_2O$) is used as a food additive in many African countries. It tenderizes foods and meat and reduces the cooking times for cowpeas. Trona also inactivates the anti-nutritional factors in jackbean seeds (Fagbenro, Adeparusi and Jimoh, 2004).
[2] NA = not available.

6. PROBLEMS AND CONSTRAINTS OF TILAPIA FEEDS AND FEEDING

In the Conference on Aquaculture in the Third Millennium, which was held in 2000 in Bangkok, Thailand, it was reported (Machena and Moehl, 2001) that:

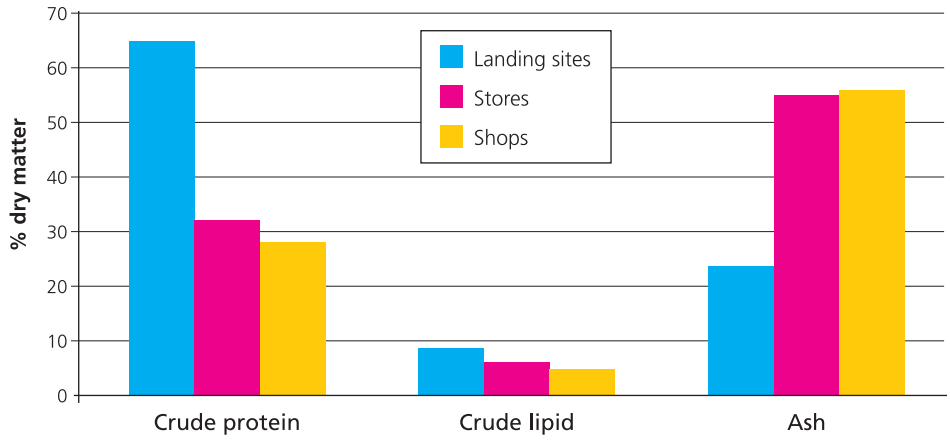
- feed is one of the major problems facing aquaculture expansion in SSA;
- the main aquafeed problems are: poor quality, little availability and the varying requirements of different species;
- farm-made feeds are dominant and are often based on the available agricultural by-products;
- little amounts of commercial feeds are produced by the private sector.
- imported pelleted feeds are not affordable by small- and medium-scale tilapia farmers, due to their high prices; and
- high transport costs and poor transport and storage infrastructure are major constraints facing the aquafeed industry in SSA.

Ten years later, the situation is still almost the same. Problems related to feed handling, transport costs, quality issues and storage infrastructure still exist. Commercial aquafeed mills are also still few because commercial production is not cost-effective and the market does not justify industrial-scale production. Therefore, organic and chemical fertilizers offer options for many small- and medium-scale farmers. Locally made aquafeeds also provide justifiable alternatives and play a significant role in aquaculture production across the region.

High transport costs, poor transport and storage infrastructure and bad feed supply chains remain key factors hampering aquaculture development in SSA. Feed and feed ingredients are often transported to remote areas where aquaculture is practiced. Transport infrastructure in many areas is poor, and some roads are not usable during the rainy seasons in many countries (Randriamiaran, Rabelahatra and Janssen, 1995; Machena and Moehl, 2001).

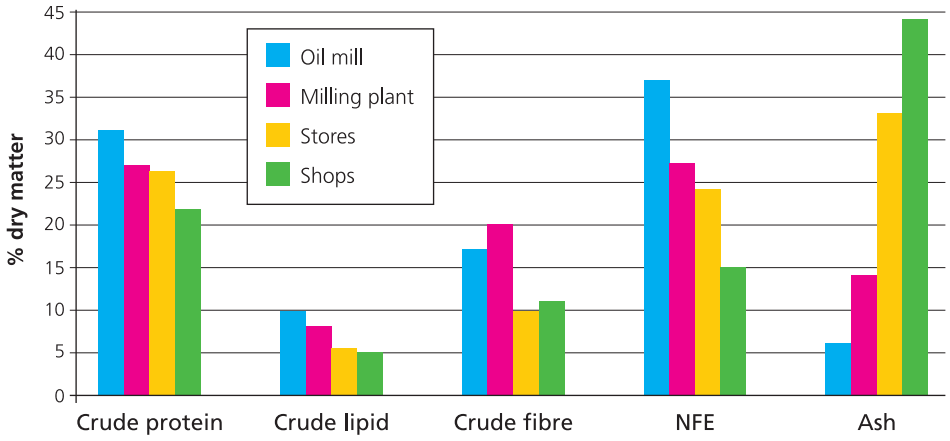
The quality of fish feed may also be subjected to sharp deterioration during storage and distribution through the supply chain. In a recent and comprehensive study, Nalwanga *et al.* (2009) investigated the nutrient content of selected feed ingredients, including fishmeal, cottonseed cake and sunflower cake at different points of the supply chain in Uganda and Kenya. These authors also compared the determined nutrient composition of commercial fish feeds with their labelled nutrient contents. The composition of those tested substantially differed from the values labelled by the manufacturers (Table 12). Market prices of feed ingredients along the supply chain had also been substantially increased. Nalwanga *et al.* (2009) also found that serious deterioration had occurred in the quality and composition of feed ingredients between the primary outlets and the stores or shops (Figures 10 and 11).

FIGURE 10
Nutritional composition of fishmeal at different points in the supply chain



Source: Redrawn from Nalwanga *et al.* (2009).

FIGURE 11
Nutritional composition of cottonseed cake at different points in the supply chain



Source: Redrawn from Nalwanga *et al.* (2009).

TABLE 12
Examples of crude protein (CP) content (%) as labelled and as analysed for fish feeds in Uganda

Type of feed	Fry pellets	Starter 1 pellets	Starter 2 pellets	Grower 1 pellets	Grower 2 pellets	Grower 3 pellets
Labelled CP	44.0	36.0	35.0	32.0	32.0	28.0
Determined CP	46.7	27.2	27.5	28.9	26.5	30.1

Source: Nalwanga *et al.* (2009).

One other major challenge facing the aquafeed industry and aquaculture development in SSA is the lack of legal and regulatory frameworks for fish feed management and the environmental effects of feed uses. No regulatory standards exist on feed composition, feed performance, feed use/quota, suspended solids, effluent treatment, enrichment, etc. In other words, none of the countries in the region have adopted any codes of conduct (COC) or best management practices (BMP). Therefore, fish feed certification is lacking in the region, and there is no assurance that fish farmers receive quality feeds.

7. RECOMMENDATIONS

In order for the aquafeed industry in SSA to be sustainable and cost-effective, the governments of countries of the SSA Region should:

- Enact legislation and regulations necessary to guarantee the proper management, quality and safety of aquafeeds. Such legislation must specify feed standards, establish basic procedures for enforcement and provide guidelines to be respected by the industry and practitioners in the production and use of aquafeeds. Legislation should also specify feed composition, manufacturing, handling, storage and use. Governments must also undertake periodic reviews of food/feed legislation to ensure their coherency and to reduce overlaps and conflicting jurisdictions.
- Promote domestic feed industries by reducing or removing taxes on imported feed milling machinery and basic feed ingredients.
- Develop country-specific farm-made feed formulations and promote research on tilapia nutrition and feed management, with emphasis on nonconventional feed ingredients.
- Promote the adoption of appropriate feed manufacturing guidelines and standards and develop appropriate low-cost machinery for milling, mixing and manufacture of feeds.
- Ensure aquafeed quality and safety through inspections and feed certification, and make information on the availability, quality and prices of processed feeds and feed materials available to producers through proper information dissemination systems.
- Improve capacity building for the aquafeed industry and provide the necessary extension services and training for fish feed technologists, including training on commercial and on-farm feed formulation, pelleting and manufacture.
- Adapt and improve low-cost feed drying technologies and develop appropriate storage facilities to prevent spoilage and maintain the quality of both feed ingredients and processed aquafeeds.
- Evaluate and test alternate feed ingredients and determine their optimal inclusion rates, improve the quality (digestibility and utilization) of these feed sources and evaluate their availability, accessibility, prices and nutritional values.
- Quantify the demand for animal manure in tilapia culture at the country level and devise low-cost distribution plans.
- Assist fish-producer organizations to participate actively in the development of the sector through information sharing among stakeholders, lobbying for collective bargaining and public-sector intervention, and linking with research organizations.

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On-farm feeding and feed management in tilapia aquaculture in Malaysia

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ABSTRACT

A field survey was conducted over a period of 10 months in 2007 to collect data on tilapia farming practices by small, medium and large producers in Malaysia, focusing on on-farm feed management practices and feed inputs. One hundred and four farms in both Peninsular and East Malaysia from the states of Negeri Sembilan, Pahang, Perak, Penang, Sabah, Sarawak, Selangor and Terengganu were surveyed. The major tilapia culture systems were found to be earthen ponds (46 percent), ex-tin mining pools (24 percent), and cage culture (21 percent). The dominant tilapia farmed is various red hybrid tilapia *(Oreochromis spp.)*. The farm owners are predominantly male (age range between 41 and 60 years), and about 70 percent listed aquaculture as their major source of income. About 54 percent of the farmers own the land, but these are mainly small- and medium-scale producers. Large producers in certain states operate on temporary operation licences issued by the state land office. Tilapia production occupies a small percentage of the total land available on the farm, and other agricultural activities such as livestock and vegetable farming are sometimes carried out to supplement farm income; about 76 percent of farm land remains unused. Production function analysis suggested that cage culture was the best-performing system with the highest production yield. The average feeding costs of the surveyed farms were almost 63 percent of the production costs. High production cost was found to be caused by the use of commercial tilapia feeds in over 90 percent of the farms surveyed. The three major commercial aquafeed brands used by the tilapia farmers were Cargill (33 percent), Star Feeds (30 percent) and Dindings (21 percent). Analyzed proximate composition of various feed samples mostly tallied with the composition declared by feed manufacturers. Supplementary feed inputs, such as cattle and poultry pellet feeds, farm-made feeds, copra meal, palm kernel cake, poultry intestines, animal carcasses and kitchen waste, are used by small and medium producers to reduce feeding costs. Farm-made feeds varied greatly in their proximate composition depending on the ingredients used. Inorganic commercial fertilizers for pond

water fertilization are not commonly used in tilapia farms in Malaysia. In conclusion, technical aspects of tilapia farming such as the use of cost-effective feeds and better tilapia strains need to be given special emphasis in order to boost the production of tilapia with maximum profitability. Two industries identified as having the potential to supply much needed locally available alternative feed ingredients are the oil palm and poultry industries.

1. INTRODUCTION

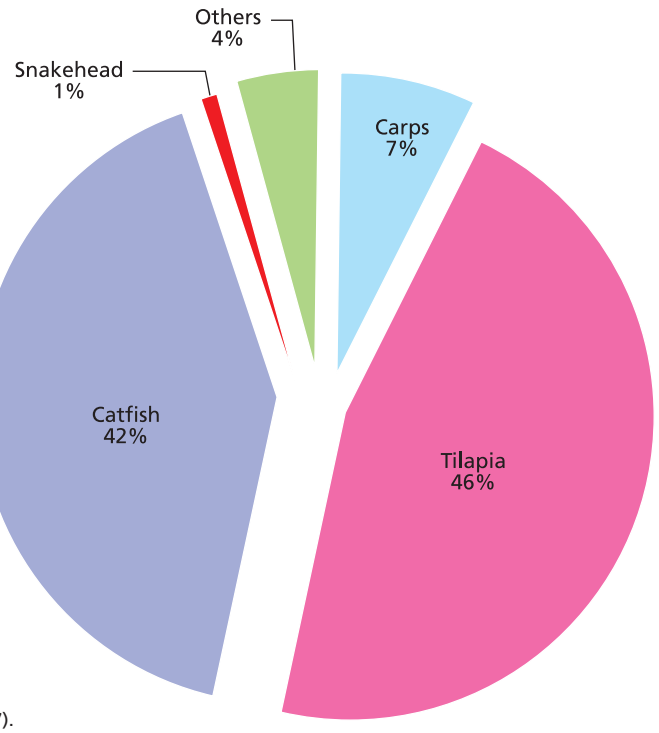
In Malaysia, the fisheries sector contributed 1.42 million tonnes of seafood valued at MYR5.3 billion[1] (US$1.66 billion) in 2007 (DOF, 2007). The sector can be divided into two main subsectors, namely the marine capture fisheries industry and the aquaculture industry. The marine capture fisheries subsector accounted for about 84 percent of total seafood supply. The inland capture fisheries subsector is very small, contributing less than 1 percent of the total seafood supply. The aquaculture industry contributed 268 500 tonnes (about 16 percent) to the seafood supply, valued at about US$0.41 billion (DOF, 2007). Due to very favourable government policies (MOA, 1999), this subsector has great potential for further expansion (Ng 2009a,b). The local aquaculture industry recorded annual growth rates of about 10 percent from 1993 to 2007. The presence of vast bodies of inland freshwaters and the long coastlines of Peninsular Malaysia and East Malaysia augurs well for future aquaculture development. Malaysia is also a major global supplier of ornamental fish and aquatic plants.

Freshwater aquaculture contributed about 26 percent of the total aquaculture production in 2007 (DOF, 2007), with production of 70 064 tonnes arising from various culture systems such as ponds, ex-tin mining pools, cages and tanks/pens (18, 4, 3 and 1 percent, respectively). The use of ex-mining pools for freshwater fish farming is unique to Malaysia due to the many abandoned such sites that are now filled with water. Fish are either released into these pools of various sizes and shapes or are farmed in small cages suspended in the water. The three major freshwater species groups farmed are the tilapias, catfishes and carps, constituting 46, 42 and 7 percent of total freshwater aquaculture production (Figure 1). Other cultured freshwater species include snakeheads, marble gobies and freshwater prawns. About 32 023 tonnes of tilapia were produced in 2007. Unlike other countries where Nile tilapia is the major farmed species, the major tilapia species farmed in Malaysia is the red hybrid tilapia (*Oreochromis* spp.), which accounts for about 82 percent of total tilapia production; the remaining production consists of the 'black tilapias' [Nile tilapia (*O. niloticus*), Mozambique tilapia (*O. mossambicus*) and hybrids thereof]. Red hybrid tilapias are generally of unknown genetic status and are bred to enhance appearance and marketability. The original red hybrid tilapia introduced into Malaysia was probably a hybrid of *O. niloticus* with *O. mossambicus*. There is also a very pale-pink hybrid variety (sometimes called the Malaysian white hybrid tilapia) that is known for its fast growth rates. The major catfish species farmed are the African catfish (*Clarias gariepinus* or its hybrids), various *Pangasius* species and the bagrid catfish (*Mystus nemurus).* Total catfish production in 2007 was 28 875 tonnes. Various carps such as grass carp (*Ctenopharyngodon idella*), silver barb (*Barbonemus gonionotus*), common carp (*Cyprinus carpio*) and bighead carp (*Hypophthalmichthys nobilis*) are farmed, but production is relatively small, amounting to about 5 005 tonnes in 2007. Aquaculture production of the giant freshwater prawn (*Macrobrachium rosenbergii*) amounted to only about 246 tonnes in 2007.

The Malaysian Government targeted a production of 600 000 tonnes of seafood from aquaculture by 2010 (Ng, 2009a) under the Third National Agricultural Policy (NAP3). NAP3 is a guideline formulated by the Malaysian Government for the development of

[1] US$1.0 = MYR3.2

FIGURE 1
Freshwater fish species cultured in Malaysia



Source: DoF (2007).

the agriculture sector, which includes fisheries. It emphasizes development towards a fully modern and commercialized capture fisheries and aquaculture industry through exploitation of available resources on a sustainable basis. NAP3 promotes commercial-scale aquaculture. The initial target was to have an estimated contribution of 123 500 tonnes from freshwater fish production by 2010, of which tilapia will be the major contributor (Ng, 2009a). Tilapia farming activities in Malaysia are therefore expected to undergo rapid development in the foreseeable future.

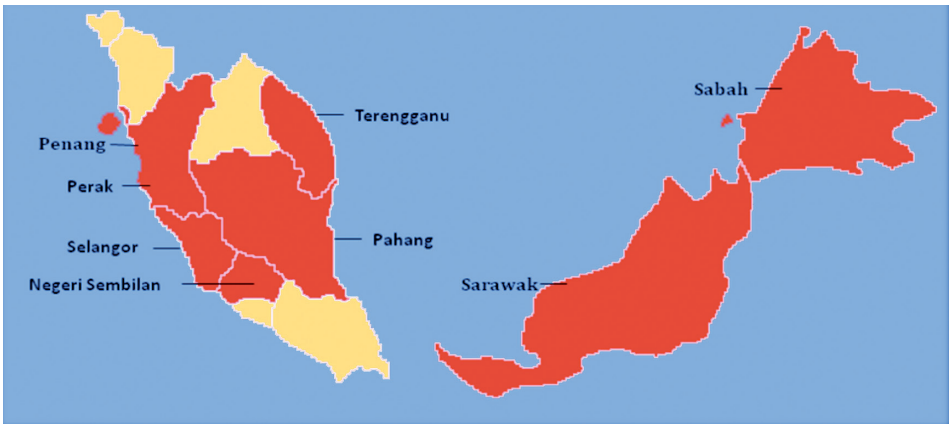
In view of this development, three organizations (Universiti Sains Malaysia, University of Guelph and the WorldFish Center) decided to conduct a comprehensive field survey of tilapia farming in Malaysia to collect baseline information about the industry. This was the first such study carried out on this industry in the country. It was hoped that the data collected could contribute to the formulation of appropriate policies and guidelines to expand tilapia farming on a sustainable basis. Data such as the socio-economics of farmer households, land status, water source, labour profile, support services availability, culture systems, access to tilapia fry for stocking, feed inputs, feeding practices, production costs, marketing of tilapia, and constraints faced by farmers were collected. Data were compiled based on on-farm interviews, farm measurements, photographs taken and the analysis of feed samples collected on the surveyed farms (WFC, 2009).

2. TILAPIA FARM CHARACTERISTICS

2.1 Number of farms and culture systems

A total of 104 farms was surveyed throughout Malaysia (Figure 2, Table 1). More farms were surveyed in Sabah, Perak, Selangor, Negeri Sembilan and Sarawak than in others due to the availability of farmers on the days the areas were visited. The overall distribution of farm culture systems surveyed is shown in Figure 3.

FIGURE 2
States in Peninsular Malaysia and East Malaysia where the tilapia farm survey was conducted



Source: Field survey (2010).

TABLE 1
Number of farms surveyed in each state

State	Number of Farms
Negeri Sembilan	22
Pahang	5
Perak	22
Pulau Pinang	4
Sabah	19
Sarawak	13
Selangor	17
Terengganu	2

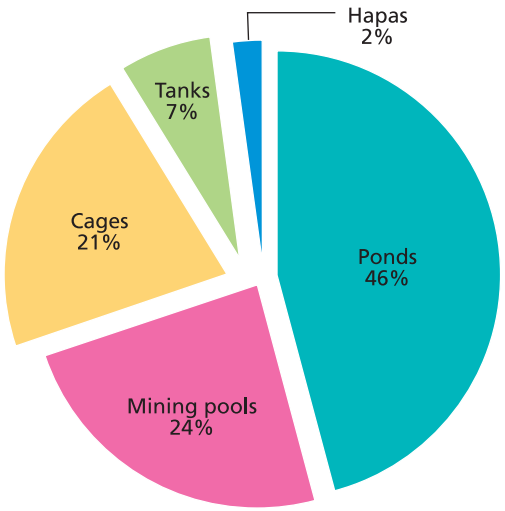
Source: Field survey (2010).

A majority of the farms surveyed is using earthen ponds, either man-made or ex-mining pools. Up to 78 percent of the culture systems surveyed in Sabah and 91 percent in Negeri Sembilan are constructed earthen ponds. In Perak and Selangor, 68 percent and 76 percent, respectively, of total farms surveyed are using ex-mining pools. In contrast, states with great rivers and reservoirs, such as Pahang, Terengganu and Sarawak, prefer to run their tilapia operations using floating cages. Despite the smaller number of tilapia cage farms surveyed, compared to pond systems, it should be noted that farming systems, feed inputs, stocking density and other farming practices are often standardized for all the tilapia cage farmers in a particular district or waterbody. Some of these cage farmers are set up as clusters or cooperatives by governmental or semi-governmental agencies. Data collected from surveyed farms were therefore considered representative of the many tilapia farms present in the specific localities in Pahang, Terengganu or Sarawak having a preponderance of these cage-culture systems.

2.2 Land ownership and scale of production

Many farmers in Malaysia do not own the land and/or waterbody from which tilapia is produced. The land status of farms surveyed can be classified into four categories, namely, land owners (54 percent); under temporary operation license (TOL) (22 percent);

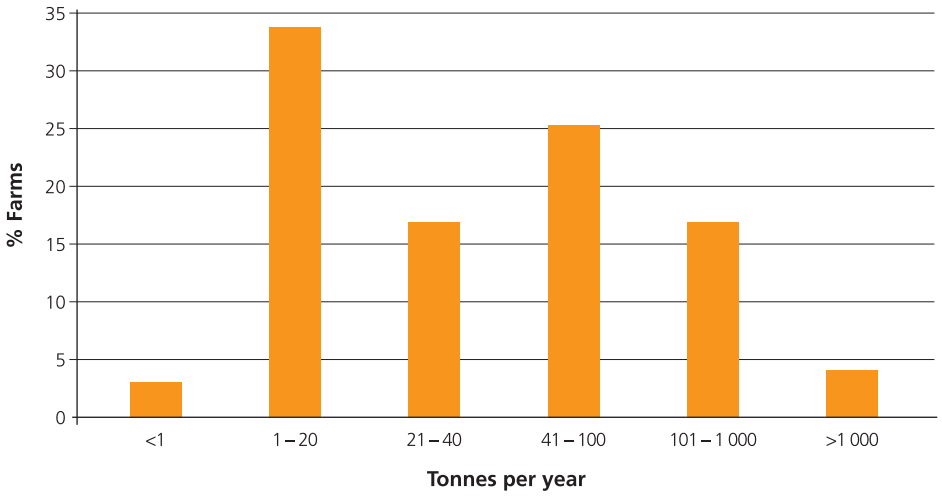
FIGURE 3
Types of tilapia culture systems surveyed



Source: Field survey (2010).

state-owned (12 percent); or rented (12 percent). About half of the survey respondents own the land to their farms, but these are mainly small-scale producers and traditional backyard farmers. Medium-scale and large-scale tilapia producers, especially those in Perak, Selangor and Negeri Sembilan, are operating on TOL and rented land. The rates for license or rental fees are charged yearly based on land size and vary by state and also by district. The respective state governments have the authority to reclaim any land on TOL status for state or federal use at anytime. In contrast, farmers operating from state-owned farms are associated with government development projects implemented by the Federal Land Consolidation and Rehabilitation Authority (FELCRA), the Federal Land Development Authority (FELDA) or the local Department of Fisheries (DOF) and do not need to pay license fees or land tax. This is done through efforts by the Malaysian Government to improve the livelihoods of rural communities by creating employment and work opportunities. The distribution of surveyed farms according to their scale of tilapia production is shown in Figure 4.

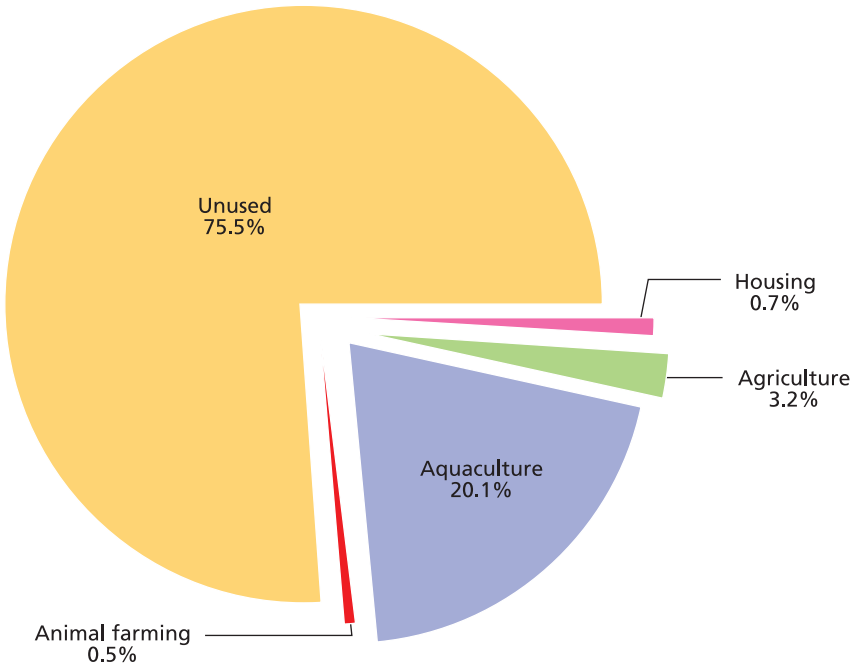
FIGURE 4
Distribution of tilapia farms surveyed based on their total tilapia production per year



Source: Field survey (2010).

The 'temporary' and rented land status of many of the larger producers has somewhat dampened the desire of these tilapia farmers to expand their scale of production due to the perceived greater risk and loss in capital investment should the state government decide to take back the land. The lack of suitable funding was another factor given by the survey respondents as to their limited usage of this farm land for tilapia production. It is therefore not surprising that none of these farms were fully utilizing the land resources around them, including the most intensively managed farms. On average, tilapia production occupies about 20 percent of the total land available on the farm, and other agricultural activities, such as livestock and vegetable farming are sometimes carried out to supplement farm income. About 76 percent of farm land remains unused (Figure 5).

FIGURE 5
Distribution of land use on tilapia farms



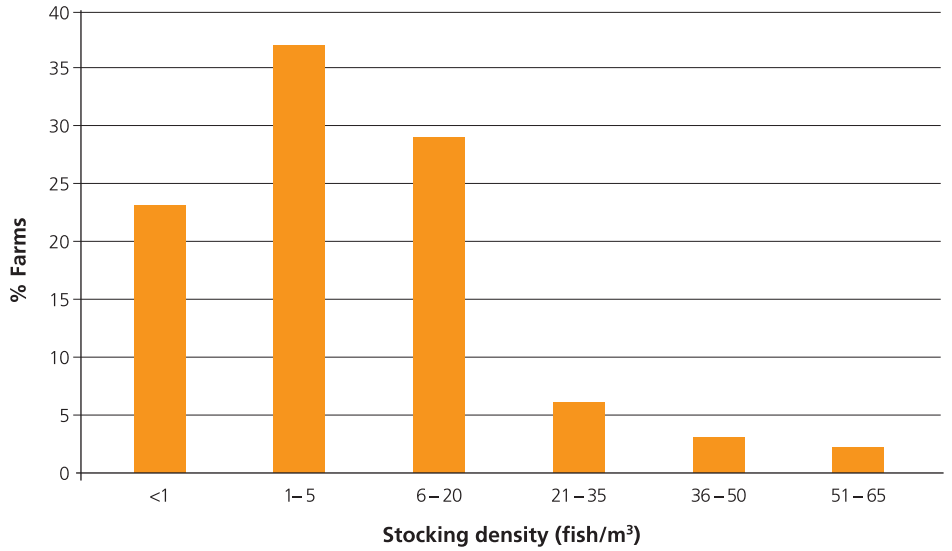
Source: Field survey (2010).

2.3 Farm management and labour profile

Tilapia stocking densities (Figure 6) varied depending on culture system, fish stocking size and the financial ability of the farmer to purchase seed. Most farms stock one to four cycles per year. The size of seed varied from 0.5 to 11.4 cm, with the majority of farmers using sizes below 5.1 cm. Seed are purchased from private or state hatcheries or are produced within the farm itself.

The stocking density and frequency of restocking often determined the amount of labour needed by the farmer. Labour cost is a major contributor to the total production costs. There are four categories of labour employed by the farms: foreign workers, tribal natives, locals and family members. The cost of hiring full-time foreign workers is slightly higher, ranging between US$220 and US$375 per month. The tribal natives are the cheapest labour force, being hired only on a daily basis (at about US$14 per day for 4 to 5 hours of work) when extra hands are required. Local Malaysians (usually educated) and family members are paid the highest at around US$375–625 per month. The wages are very much dependent on locality. However, workers in commercial farms

FIGURE 6
Stocking density of tilapia farms

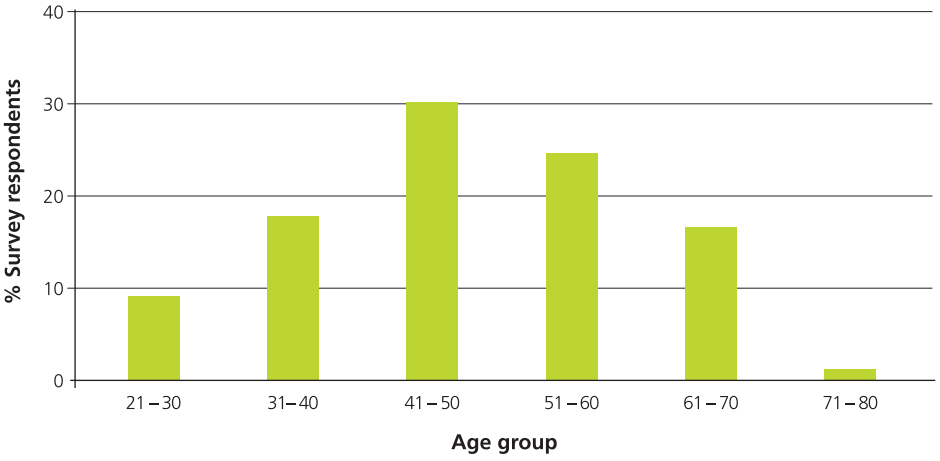


Source: Field survey (2010).

generally attained higher pay than those working in non-commercial farms. In addition, farm workers received relatively higher pay in West Malaysia than in East Malaysia.

Throughout the entire survey, only three female farmers were encountered. Their average age was 56 years, and only one of them was farming fish as her major occupation. Overall, 70 percent of the respondents practiced aquaculture as a major source of income. Of the 73 major farmers, 46 had no other source of income. The age range with the highest number of respondents was between 41 and 50 (Figure 7). Farmers from Sabah were relatively older men (mainly retirees) who run the operation out of interest and to generate extra income. The state governments of Perak, Pahang, Terengganu and Sarawak have introduced various incentive programmes to attract young and educated people to the aquaculture industry but, judging from the relatively small number of farmers below 40 years of age, the response seems lukewarm.

FIGURE 7
Number of survey respondents from the different age groups



Source: Field survey (2010).

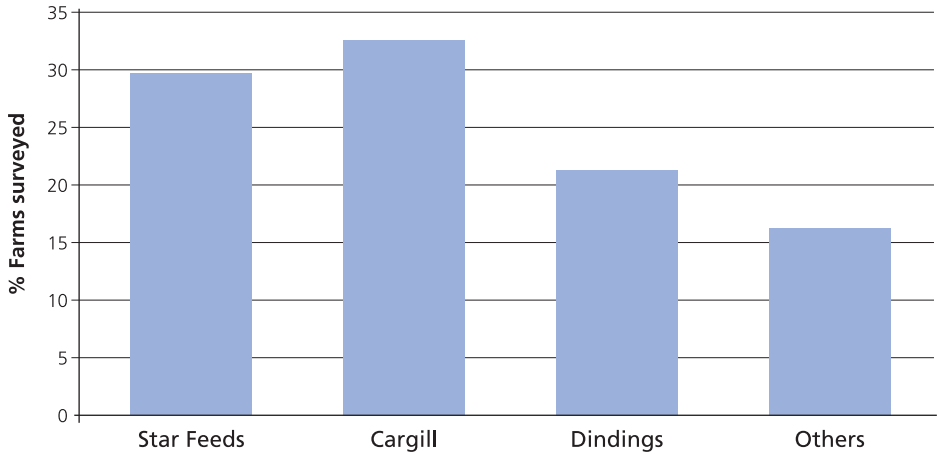
3. FEED INPUTS AND FEED MANAGEMENT PRACTICES

3.1 Commercial feeds

Four main categories of commercial tilapia feeds are available in Malaysia. Pre-starter feeds for tilapia fry at the hatchery stage have about 34 percent crude protein and are priced at US$880–1 100 per tonne. Starter feeds for the nursery and grow-out phase are formulated to contain 32–34 percent crude protein and are sold at US$790–840 per tonne. Grower feeds cost between US$730 and 800 per tonne and contain about 25–28 percent protein. Lastly, finisher feeds cost from US$690 to 750 per tonne, with a crude protein content ranging from 18 to 25 percent. All tilapia feeds used in Malaysia are produced locally. Feed prices vary slightly among the different feed manufacturers and are also dependent on locality. Feed prices in East Malaysia are higher than in other parts of Malaysia due to the additional transportation costs across the South China Sea. Bulk purchases of feeds by the larger producers are usually given a discount by the feed manufacturers. Feeds are packaged in 20 kg bags when sold.

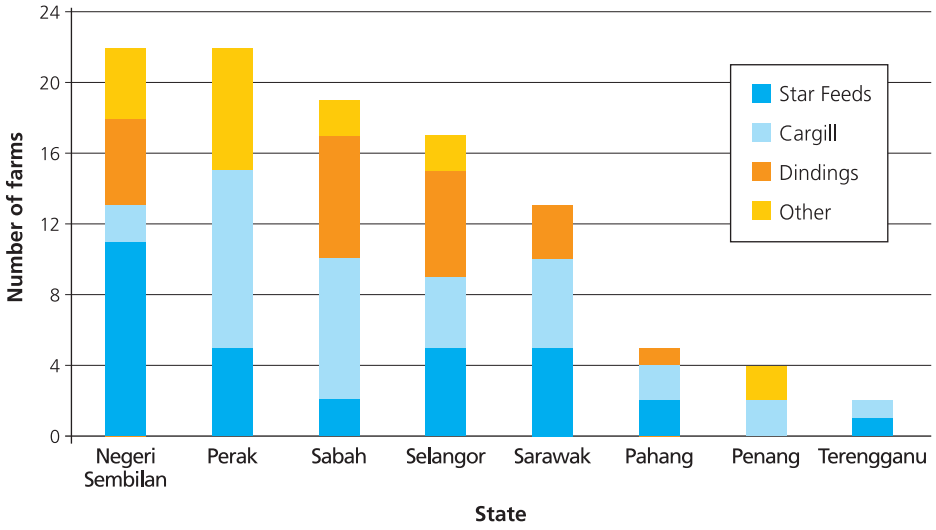
About 84 percent of the feed samples collected from the surveyed farms were commercial feeds, which included the three major brands: Cargill, Dindings and Star Feeds (Figures 8 and 9). Tilapia feeds from smaller local feed mills are also used by tilapia farmers. Farmers tended to practice brand loyalty and usually only one particular brand of tilapia feed can be found at an individual farm. Tilapia farms mainly used starter and grower feeds during the culture period. In an attempt to improve growth, some farmers used starter feeds from stocking to harvesting, despite their higher costs as compared to grower feeds. In one farm, the farmer mixed starter and finisher feeds for use in grow-out production. Pre-starter feeds are also used by some farmers, but these are restricted to nursery farms and hatcheries. The cheaper finisher feeds are often used towards the end of the culture period to reduce the cost of production in traditional or small-scale farms. Figure 8 shows the number of farmers using the various brands of commercial feed. Commercial chicken, duck and cattle feeds are also used by some small-scale producers in an effort to reduce feeding costs. These livestock feeds and other tilapia feeds produced by smaller feed mills, as well as the occasional catfish and marine fish feeds observed on farms, are categorized as ‘others’ in Figures 8 and 9.

FIGURE 8
Number of farms using various brands of commercial tilapia feed



Source: Field survey (2010).

FIGURE 9
Distribution of feed brands used in tilapia farms categorized by state



Source: Field survey (2010).

The declared proximate composition of various commercial feeds as noted from the feed bags during the field survey is presented in Table 2. Some of these feeds were collected and taken back to the Fish Nutrition Laboratory at Universiti Sains Malaysia for chemical analysis. All proximate analysis was conducted using standard methods (AOAC, 1997). The analyzed proximate composition of feeds is generally within the stipulated values as declared by the feed companies (Tables 3 and 4). Crude protein content depends on whether the tilapia feed is pre-starter, starter, grower or finisher type, with analyzed values generally exceeding the minimum content declared by feed manufacturers. Analyzed crude lipid content is generally higher by 1 to 3 percent of the minimum content declared by the feed manufacturer. Ash and crude fibre content are not always revealed by feed producers but, when declared, generally do not exceed the maximum levels. The duck feed sampled had 21.5 percent protein, 10.2 percent lipid and low fibre content, but the chicken feed sampled contained low protein and high fibre and ash content and thus may not be suitable for smaller-sized tilapia (Table 4).

3.2 Feeding practices for commercial feeds

Feeding is carried out manually by scattering feed over the side of the ponds/cages or with the use of automatic feeders (Figure 10). In cage culture, feed bags are commonly placed near the cages under direct sun for ease of access to the feeds. Medium and large producers usually feed 3–5 percent of fish body weight per day, while traditional and small producers feed depending on the availability of feedstuffs. Since manual feeding is mostly carried out by hired farm workers, there is a tendency to overfeed, with the misconceived idea that fish given more feed will grow faster. On the farms of larger producers, farm workers are generally better trained, and more optimal feeding rates can be expected. With the exception of commercial large producers, estimation of feed conversion ratios (FCR) in smaller farms is difficult, due to unmonitored feeding of pelleted feeds, and is further complicated by the occasional use of supplementary feeds of various types (see section 3.3).

TABLE 2
Declared proximate composition (%) of commercial feeds used by tilapia farmers

Feed sample	Feed type	Dry matter	Ash	Crude protein	Crude lipid	Crude fibre
Star Feeds						
TL 9991	Starter	min 88	NS[1]	min 32	min 4	NS
TL 9992	Grower	min 88	NS	min 28	min 4	NS
TL 9993	Finisher	min 88	NS	min 25	min 4	NS
TP-1	Starter	min 88	NS	min 32	min 4	NS
TP-2	Grower	min 88	NS	min 28	min 4	NS
TP-3	Finisher	min 88	NS	23–25	min 4	NS
9932	Fish Feed	min 88	NS	min 16	min 4	NS
9974	Marine Feed	min 88	NS	40–42	min 4	NS
9910	Catfish starter	min 88	NS	min 32	min 4	NS
Dindings						
92000C	Starter	min 89	NS	min 32	min 4	max 8
92000	Starter	min 90	max 10	min 32	min 5	max 5
92100	Grower	min 90	max 10	min 28	min 5	max 5
92900	Finisher	min 90	max 10	min 20	min 5	max 5
92300	Finisher	min 90	max 10	min 23	min 5	max 5
92500	Finisher	min 90	max 10	min 18	min 5	max 6
Cargill						
6103	Pre-starter	min 89	NS	min 34	min 4	max 5
6113-S	Starter	min 89	NS	min 32	min 6	max 6
6133-S	Finisher	min 89	NS	min 18	min 4	max 6
6113	Starter	min 89	NS	min 34	min 4	max 6
6123	Grower	min 89	NS	min 28	min 4	max 5
6083	Super	NS	NS	18–20	NS	NS
6353	Catfish feed	min 90	NS	min 32	min 4	NS
Hong Lee						
9922	Finisher	min 88	max 15	min 20	min 8	max 7

[1]NS = Not stated.

Source: Field survey (2010).

TABLE 3

Analyzed proximate composition (% dry matter basis) of the three major commercial tilapia feed brands (mean±SE for 3 analyses)

Sample	Feed type	Dry matter	Crude protein	Crude lipid	Crude fibre	Ash	NFE[3]
Company A							
n=3[1]	Starter	92.1±0.6	37.7±0.6	5.6±0.5	2.1±0.2	9.0±0.3	45.6±0.6
n=2	Grower	91.4±0.2	32.6±0.1	6.2±0.2	2.2±0.2	8.9±0.1	50.0±0.2
n=1	Finisher[2]	90.4±0.1	32.8±0.0	6.9±0.1	3.3±0.1	9.3±0.0	47.8±0.0
Company B							
n=2	Starter	93.1±0.3	38.0±0.2	5.1±0.4	3.3±0.3	8.7±0.5	44.9±0.0
n=1	Grower	91.5±1.1	26.3±0.2	5.8±0.4	6.1±1.2	8.1±0.2	56.1±1.7
n=5	Finisher	90.9±0.0	21.7±0.1	5.9±0.3	4.6±0.3	8.3±0.0	59.6±0.2
n=1	Unknown	91.4±0.0	33.9±0.0	7.0±0.2	3.9±0.0	8.4±0.0	46.9±0.2
Company C							
n=1	Pre-starter	93.9±0.0	39.5±0.2	4.8±0.1	2.0±0.0	9.5±0.1	44.2±0.1
n=1	Starter	91.1±0.1	35.0±0.1	7.6±0.1	2.6±0.0	7.9±0.0	47.0±0.1
n=1	Grower	92.0±0.0	28.2±0.5	5.5±0.5	2.9±0.1	10.4±0.0	53.1±0.6
n=1	Finisher	90.8±0.0	24.4±0.1	5.1±0.0	3.2±0.4	9.4±0.1	57.9±0.0
n=1	Finisher	92.7±0.0	19.4±0.1	5.5±0.3	6.0±0.1	10.2±0.0	58.9±0.4
n=1	Unknown	89.3±0.0	39.6±0.1	5.7±0.7	3.3±0.5	8.7±0.0	42.7±0.7

[1]n = Number of farms from which the feed was collected. Samples were analyzed as 3 replicates for each farm
[2]According to the farmer
[3]NFE = Nitrogen-free extract = 100 – (% ash + % protein + % lipid + % fibre).
Source: Field survey (2010).

TABLE 4

Analyzed proximate composition (% dry matter basis) of other commercial pelleted feeds, farm-made feeds and feed inputs found at surveyed tilapia farms (mean±SE for 3 analyses)

Sample	Feed type/company	Dry matter	Crude protein	Crude lipid	Crude fibre	Ash	NFE[2]
n=1[1]	Star Feeds catfish starter	91.3±0.0	38.8±0.8	5.3±0.0	2.8±0.1	8.1±0.0	45.0±0.7
n=1	Gold Coin fish feed	91.1±0.0	38.7±0.1	5.2±0.1	3.9±0.1	9.7±0.0	46.4±0.1
n=1	Hong Lee tilapia feed	91.8±0.0	22.3±0.1	8.6±0.1	11.1±0.2	10.0±0.1	48.0±0.1
n=1	Duck feed	88.4±0.1	21.5±0.4	10.2±0.2	3.6±0.0	8.5±0.2	56.2±0.7
n=1	Chicken feed	91.7±0.0	8.9±0.1	6.5±0.1	16.6±0.2	32.0±0.1	35.9±0.2
n=1	Palm kernel cake	89.5±0.0	11.1±0.1	3.7±0.1	22.2±0.3	12.5±0.0	50.5±0.1
n=1	Fishmeal	89.9±0.1	63.5±0.2	9.1±0.1	2.3±0.1	24.9±0.1	0.2±0.3
n=1	Starch	87.2±0.1	0.3±0.1	0.0±0.0	0.4±0.1	0.3±0.0	99.0±0.1
n=1	Farm-made feed (Sabah)	90.5±0.6	20.9±0.1	17.1±0.1	12.5±0.5	11.9±0.1	37.5±0.2
n=1	Farm-made feed (Penang)	54.5±0.3	27.9±0.4	4.8±0.2	12.5±0.6	19.5±0.3	35.3±0.6

[1]n = Number of farms from which the feed was collected. Samples were analyzed as 3 replicates for each farm
[2]NFE = Nitrogen-free extract = 100 – (% ash + % protein + % lipid + % fibre).
Source: Field survey (2010).

FIGURE 10
Manual feeding (top left), auto feeder (top right) and feed bag placed near tilapia cages (bottom centre)

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Commercial tilapia feeds are mostly extruded floating feeds, but some small- and medium-scale farms do use sinking pellets, which are cheaper. In order to monitor the feeding activity of fish fed these sinking pellets, some farmers resort to using feeding trays, which are suspended close to the water surface (Figure 11). The feeding activity and amount of feed needed by the fish can therefore be monitored more closely. In very large ponds and in ex-mining pools, a feeding platform and a feeding enclosure made of polyvinyl chloride (PVC) pipes can sometimes be seen (Figure 11, bottom). This designated feeding area allows the farmer to monitor the condition of the fish and their feeding activity. Fish are trained to congregate in this feeding area during meal times, and the large feeding enclosure prevents floating feeds from being dispersed over the pond surface by the wind. Any unfinished feeds can therefore be observed by the farmer and the feeding rate adjusted accordingly to the actual requirement of the fish.

3.3 Supplemental and farm-made feeds

Farm-made feeds are not a major feed input in tilapia farms in Malaysia. Nevertheless, these feeds are made and used by some small- and medium-scale producers as a supplement to commercial feeds. Due to the wet/moist nature of these farm-made feeds and the logistical problems for cold storage during the survey, we only managed to bring back two samples to the laboratory for proximate analysis. The proximate composition of the feed from a farm in Sabah contained about 21 percent crude protein but had a very high lipid level of 17 percent (Table 4). The farm-made feed collected in Penang had good protein and lipid levels but was high in ash content. The formulations of these two feeds are not known. Farmers tend to change the ingredients used depending on the availability of feedstuffs and by-products and their relative costs. It can therefore be expected that the proximate

FIGURE 11
Feeding trays used in floating cages when sinking pellets are used (top photos) and feeding enclosure and platform constructed in a large ex-mining pool to congregate the tilapia during meal time (bottom centre)

COURTESY OF W.-K. NG.

composition of these feeds will vary depending on season and locality. Feeds made on-farm are sun-dried if not immediately used (Figure 12). Other than these more 'advanced' farm-made feeds, where there is an attempt to mix various ingredients to get an intended nutrient composition suitable for tilapia culture, some farmers merely ferment, grind or mix one or two agricultural wastes or by-products and feed these to tilapia. These can therefore be classified as simple farm-made feeds or supplementary feeds. During the field survey, we noticed farmers using fermented palm oil mill effluent (POME) and a corn-based feed derived from discarded corn kernels (Figure 13).

Supplementary feed inputs used by smaller producers included copra meal, palm kernel cake (PKC), poultry intestines and kitchen wastes (Figure 13). Malaysia has a very extensive oil palm industry where PKC is a by-product from palm oil production. Research into the use of PKC has reported successful incorporation of low levels in diets formulated for tilapia (Ng and Chong, 2002; Ng *et al.*, 2002; Ng, 2004). However, on its own, PKC is not a suitable complete feed for tilapia, due to its low protein and high fibre content (Table 4). Nevertheless, it is readily available. Occasionally, aquatic macrophytes, terrestrial plant leaves and wild berries are also placed in tilapia ponds and cages, especially in small traditional farms (Figure 14).

In some farms, tilapia is farmed alongside African catfish but in separate ponds. In these farms, we noticed various cooking equipment, such as large woks, containers and boilers at the farm site (Figure 15). These apparatus are used to cook poultry and fish carcasses, which are later ground up in a meat grinder, sometimes mixed with flour or rice bran and fed to the catfish. It is possible that some of these cooked poultry and fish carcasses are also used to feed tilapia, as we noticed some large cooking woks along the pond dikes of tilapia ponds.

FIGURE 12
Farm-made feeds being dried under the sun beside the fish ponds (top photos) and the crude nature of the pellets made on-farm using basic pelleting equipment (bottom centre)

COURTESY OF W.-K. NG.

None of the commercial large producers use any farm-made or supplementary feed inputs or animal carcasses to feed tilapia. In these farms, tilapia are fed only with manufactured pelleted feed under very hygienic conditions. However, in the farms of a few medium-scale producers and especially in small-scale producers, supplementary feeds are used to reduce feeding costs.

3.4 Feed cost contribution to production

The mean feeding cost of the surveyed farms worked out to be almost 63 percent of the total production cost. Feed costs as a percentage of the production costs ranges from ~50 percent in Negeri Sembilan to ~72 percent in Pahang (Table 5). Feed costs are therefore the highest contributor to the cost of tilapia production in Malaysia. Mean labour and fingerling costs are also major contributors to the overall production cost (both ~13 percent). However, though never as high as feed costs, these costs were much more variable among the surveyed farms. Fry costs ranged between extremes of ~2 percent (Perak) and nearly 24 percent (Pahang); labour costs varied between <4 percent (Penang) and >24 percent (Selangor). The cost for fertilizers is very low, as only organic fertilizers (cow or chicken manure) are used in farms with earthen ponds to condition the pond before each fish stocking. There is no further use of organic fertilizers during the cultivation period, and inorganic fertilizers were not observed to be used in the farms surveyed in this study. Fixed costs include electricity, fuel, rental, land taxes, etc. Miscellaneous costs include maintenance and repairs. A breakdown of the average cost contribution of various parameters to tilapia production costs is shown in Figure 16. A more detailed breakdown in production costs organized by state is given in Table 5.

FIGURE 13
Examples of farm-made and supplementary feeds (clockwise from top left): fermented palm oil mill effluent (POME), copra cake, kitchen wastes, cooked poultry offal, palm kernel cake (PKC) and a corn-based feed

COURTESY OF W.-K. NG.

TABLE 5

Aquaculture production costs by item and state presented as percentage (%) of total costs

Cost items	Sabah	Perak	Penang	Selangor	N. Sembilan	Pahang	Terengganu	Sarawak	Mean
Labour	15.95	15.33	3.79	24.29	21.55	4.55	10.74	8.66	13.11
Fertilizers	1.88	0.42	0.11	0.73	0.19	0.01	0.00	0.08	0.43
Fry/fingerlings	7.05	2.30	20.00	3.27	13.10	23.66	21.88	15.08	13.29
Feeds	56.37	68.08	52.51	65.02	50.46	71.77	66.68	70.24	62.64
Miscellaneous1	11.43	6.66	18.43	2.70	0.92	0.00	0.00	0.50	5.08
Subtotal	92.68	92.78	94.83	96.01	86.23	99.99	99.30	94.57	94.55
Fixed costs2	7.32	7.22	5.17	3.99	13.77	0.01	0.70	5.43	5.45
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

[1]Miscellaneous costs are *ad hoc* costs such as one-time farm equipment maintenance/repair costs, losses caused by natural disasters, etc., where the amount is not fixed and is incurred irregularly.
[2]Fixed costs include monthly electricity expenses, transportation fuel charges, rental, tax and any fixed expenses due monthly or yearly, regardless of farming activity.

Source: Field survey (2010).

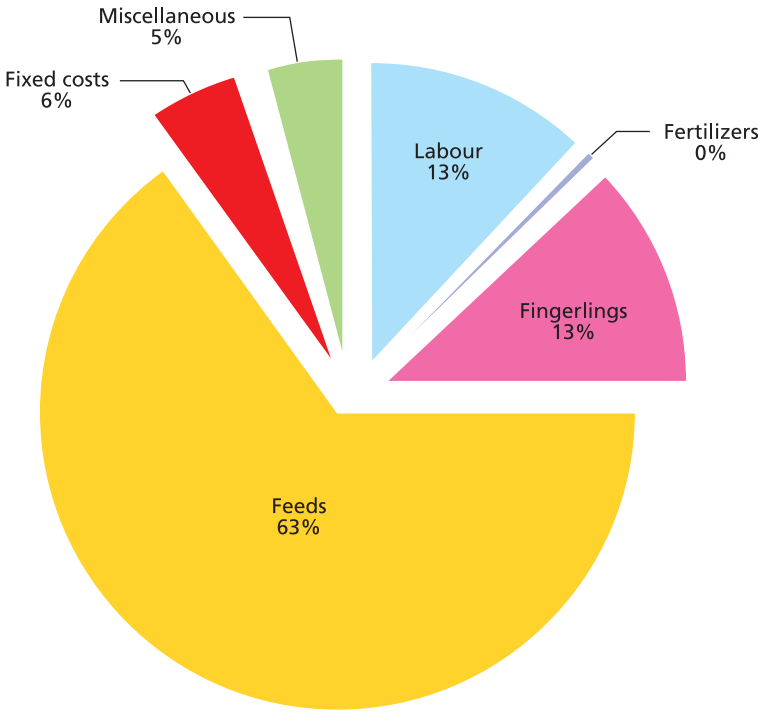
FIGURE 14
Terrestrial plant leaves (top left), aquatic plants (top right) and wild berries (bottom centre) are used by small-scale tilapia farmers as supplementary feed inputs

COURTESY OF W.-K. NG.

FIGURE 15
Examples of cooking apparatus used to cook animal carcasses to be fed to farmed freshwater fish

COURTESY OF W.-K. NG.

FIGURE 16
Average contribution of various costs to the total production cost of a tilapia farm in Malaysia



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4. TILAPIA HARVEST AND SALES

Although pricing differs according to locality, the harvesting and grading processes are usually similar (Figure 17). The tilapia farmer and the buyer are usually present throughout the harvesting process. Both parties have to agree on the grade and price for each batch of fish on the weighing machine. Fish are graded by size and overall appearance. Once the price satisfies both parties, the fish are transferred to aerated tanks and transported to designated places. Live fish are transported to the market or to restaurants. Tilapia are mainly sold live or freshly chilled in Malaysia, with some being exported to nearby Singapore. There are currently very limited local processing facilities for tilapia. In one medium-sized processing plant that we visited in Sarawak, freshly harvested fish were degutted, cleaned and frozen before being sent to fast food and 'economy rice' restaurants within the vicinity of the town in that district. However, with the entry of several new large tilapia producers in the country that target the export market, this scenario will probably change in the near future.

Farm-gate pricing for tilapia can be classified under three categories: Grade A, Grade B and Grade C, based on the size of the fish. Prices for each grade differ not only by state but also by farm within the same district. Generally, Grade A includes fish larger than 750 g and can be sold at prices ranging from US$1.63–3.13 per kg depending on negotiations between the buyer and the farmer. Fish ranging in size from 550 to 750 g are Grade B and are sold at US$1.00–1.50 per kg, while those under 550 g (Grade C) are sold at US$0.63–1.09 per kg.

FIGURE 17
Harvesting process at a community-based farm in Terengganu. Clockwise from top left; harvesting fish (farmer and buyer are seen in the background); grading; batch weighing; live fish ready to be transported to restaurant using aerated trucks

COURTESY OF W.-K. NG.

5. FUTURE PROSPECTS AND CHALLENGES

The Malaysian government has aggressively embarked on various programmes to promote the national aquaculture industry. Several 'High Impact Projects' have been launched over the last several years, and the development of supporting infrastructure for the local aquaculture industry is robust, particularly in designated areas known as 'Aquaculture Industrial Zones' that are located throughout the country. In part, these coordinated programmes have resulted in aquaculture production increasing to about 355 000 tonnes in 2008, and production is expected to continue to increase, including that of tilapia.

About the same time that this field survey was being conducted, a Norwegian company, GenoMar, established – together with a local partner company – a major tilapia production company named Trapia Malaysia Sdn Bhd. Using state-of-the-art production facilities located at Temenggor Lake in Perak, this company is expected to be a major player in the tilapia industry, producing up to 20 000 tonnes per year of tilapia in a fully integrated operation. According to the company, the bulk of the production will be for the export market. Unlike most of the present tilapia farmers, Trapia Malaysia will be farming the strain of Nile tilapia developed by their parent company in Norway, instead of the red hybrid tilapia. Similarly, a major cage-culture project for tilapia is currently being established by the Department of Fisheries in another man-made lake, Kenyir Lake, in Terengganu. Kenyir Lake is one of the largest man-made lakes in the region, with about 37 000 ha of water surface, 2 800 ha of which have been designated for the tilapia cage culture project under a 'High Impact Project' programme, which has three phases. The survey team visited tilapia cage farms located in Phase 1 of this massive project. Both these private investor and government-driven

tilapia projects, along with many others, are expected to contribute greatly to increased tilapia production in Malaysia in the near future. Nevertheless, there are some challenges and issues impeding the growth of the local aquaculture sector, and these have been discussed in detail by Ng (2009a,b). For this current review, we only discuss the issue of increasing feeding costs for tilapia farmers, and the solutions thereof.

Based on this field survey, it is obvious that the majority of tilapia farmers use commercial extruded feeds. Even small-scale farmers use these feeds, together with supplementary feed inputs and/or farm-made feeds. Self-sufficiency in tilapia feed production is therefore crucial for the local tilapia farming industry. According to industry sources, there were about 13 active aquafeed mills in Malaysia in 2007, with a total aquafeed production of about 100 000 tonnes. Extruded feeds are mainly targeted towards the tilapia farms, which currently have an estimated demand of 35 000 to 40 000 tonnes annually. Based on the gazetted extrusion production capacity of the eight major aquaculture feed mills, an annual potential production volume of 222 000 tonnes is possible (C.K. Ng, Intersea Pvt. Ltd., personal communication, 2010). The feed production capacity in the country is therefore more than enough to meet the increased demand for feeds from the anticipated expansion in tilapia farming. Several feed mills are currently producing below their potential capacity. Even in the event of shortfalls, increased tilapia feed production can be easily met by the purchase of additional extrusion equipment and expansion of feed mill production capacity.

The challenge for the tilapia feed producers is not the lack of production capacity, but the lack of locally available and cost-effective feed ingredients. Malaysia imports most of the major animal feed ingredients it requires for its livestock industry, which is dominated by the poultry industry. About 2.2 million tonnes of poultry feeds were produced in 2007 (Stanton, Emms and Sia, 2009). Compared to the poultry industry, other animal food production industries (e.g. pig, cattle and fish farming industries) are small. Table 6 shows the amounts of some of the major feed ingredients that were imported into the country in 2007 and used in the production of various commercial animal feeds.

TABLE 6
Quantity and source of animal feed ingredients imported into Malaysia in 2007

Feed ingredient	Imports (tonnes)	Major supply countries
Soybean meal	850 671	Argentina, India, China
Rapeseed cake	24 355	India, Pakistan
Other vegetable oil cakes	7 319	Singapore, China, Thailand
Fishmeal	18 659	Taiwan Province of China, Pakistan, Myanmar, Spain, Viet Nam
Rendered animal products	19 571	Australia, New Zealand
Starch industry residues	17 415	United States of America, Thailand, China
Brewery-based residues	5 505	Singapore, Australia
Vegetable wastes	33 070	Thailand, China
Whey	48 302	United States of America, Poland, France, Netherlands
Wheat[2]	2 160 000	Australia, Canada, United States of America, Argentina
Corn (maize)[1]	2 700 000	Argentina, China, India, United States of America, Thailand

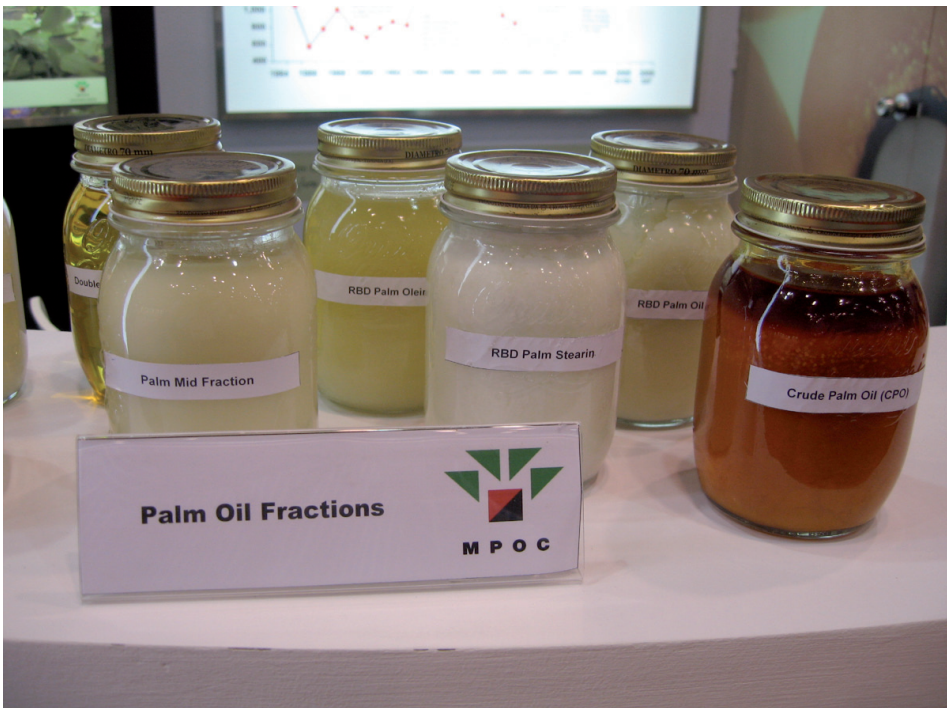
[1]Imports for both human food and animal feed usage.

Source: based on data by Stanton, Emms and Sia (2009).

Despite having a long-standing policy of encouraging the use of locally available feed ingredients in the production of animal feeds, Malaysia is an agricultural resource-poor nation, with the exception of the oil palm industry. The major protein sources in tilapia feeds produced in Malaysia consist mainly of soybean meal and other oilseed meals. Wheat and corn flour and their by-products constitute the major carbohydrate sources. Soybeans, rapeseed and wheat are not cultivated in Malaysia, and local production of corn is very limited. These ingredients are therefore imported from various countries (Table 6) for the local production of tilapia feeds. Fishmeal and fish oil are also mainly imported, as are various feed additives. With increasing demand and rising global prices of these aquafeed ingredients (Rana, Siriwardena and Hasan, 2009), the local tilapia feed producers need to explore further the use of alternative locally available agricultural products and related waste materials in their feed formulations to remain competitive.

In view of the critical need to use alternative feed ingredients in tilapia feeds, the Fish Nutrition Laboratory of Universiti Sains Malaysia embarked on several research projects to evaluate the use of products and by-products from the oil palm industry (Ng and Gibon, 2010). The fruit of the palm tree, *Elaeis guineensis*, is the source of crude palm oil (CPO) and crude palm kernel oil (CPKO). CPO overtook soybean oil in 2005 as the most produced oil in the world, with its global production reaching 43.2 million tonnes in 2008 (MPOB, 2008). Malaysia is a major producer of CPO (about 17.7 million tonnes) from an estimated oil palm planted area of 2.4 million ha. Palm oil is comparatively one of the cheapest vegetable oils in the global market (Rana, Siriwardena and Hasan, 2009). As a perennial species, palm crops produce continuously for around 25 years, guaranteeing the reliability of palm oil supply (Figure 18).

FIGURE 18
Palm oil is the most fractionated oil in the world, and various palm oil fractions have been successfully evaluated in fish feed formulations, including tilapia feeds



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To date, research has indicated that CPO and CPKO can replace up to 100 percent of added fish oil in tilapia diets without any marked negative effects on fish growth, feed utilization efficiency or survival (Ng, Lim and Sidek, 2001; Bahurmiz and Ng, 2007). This is due in part to the very low omega-3 polyunsaturated fatty acid requirements of tilapia; this fact, coupled with the low lipid levels used in commercial feeds, means that tilapia is an excellent farmed species for the successful replacement of expensive dietary fish oil. CPO contains an abundant supply of saturated (48 percent) and mono-unsaturated (42 percent) fatty acids, which makes it a superior energy source for fish diets. The use of CPO in tilapia diets has also been shown to enhance tilapia fillet shelf-life under frozen storage (Ng and Bahurmiz, 2009) and to improve fillet nutritional quality (Wang, Yuen and Ng, 2006).

As previously mentioned, ~43 million tonnes of CPO were produced globally in 2008. In palm oil refining, bleaching clay is used to bleach the crude oil to the colour desired by consumers. Usually, bleaching clay is added at about 0.5 to 2.0 percent of the weight of CPO. This would therefore give rise to an estimated annual generation of 215 000 to 860 000 tonnes of spent bleaching clays (SBC) globally. After use, this SBC may contain 20 to 30 percent adsorbed oil that cannot be recovered economically and is discarded as a waste product in landfills. The use of farmed fish as biological agents to extract residual palm oil adsorbed onto SBC is a novel way of converting waste into wealth, and is expected to benefit the oil refining and aquaculture industries as well as the environment (Ng and Koh, 2011). Feeding trials conducted with tilapia have shown that high inclusion levels of SBC are possible without negative effects (Ng and Low, 2005; Ng, Koh and Zubir, 2006). This would represent the most economical way of incorporating palm oil into the diets of farmed tilapia. Clays are considered industrial minerals and are permitted as feed additives according to Annex 1 of Directive 70/524/EEC of the European Union. SBC are bentonite clays with residual vegetable oil or animal fat from edible oil refining and are considered as materials generally recognized as safe (GRAS) under the 'intended conditions of use' by the FDA of the United States of America. Nevertheless, being a by-product, SBC have a wide range of quality, and further research on the safety aspects of SBC from palm oil refining is needed. Some fish farmers are known to use SBC in the formulation of farm-made feeds, as it provides a good source of dietary lipid and energy. Palm oil refineries gladly provide the SBC to the fish farmers without charge; it is considered a cost-saving measure for these refineries, since they do not have to spend money for its disposal. More effort is needed to make this underutilized potential feed resource known to tilapia farmers and feed producers.

Palm kernel meal (PKM) is a by-product of palm kernel oil extraction, it therefore constitutes an oilseed meal/cake. About 2.4 million tonnes of PKM were produced in 2008 in Malaysia (MPOB, 2008). Currently, most of the PKM produced in Malaysia is exported at a low price to Europe for use as feed concentrates for dairy cows to increase milk fat. PKM is an established feed ingredient for ruminants, supplying valuable dietary sources of protein, energy and fibre. The use of PKM has been evaluated as an alternative to soybean meal in tilapia diets. Despite its high fibre content and the presence of indigestible non-starch polysaccharides, low amounts can be used in tilapia diets (Ng, 2004; Lim, Bai and Ng, 2005). Higher dietary inclusion of PKM in tilapia feeds may be possible if it is pre-treated (Ng and Chong, 2002; Ng *et al.,* 2002). Further research on the use of this cheap by-product from the palm oil industry in tilapia feeds is warranted. Small-scale tilapia farmers currently use PKM as one of their feed inputs, either alone, as a ground powder, or incorporated into simple farm-made feeds (Figure 13).

Apart from various palm oil fractions, by-products and waste-products from the palm oil industry, the only other known potential major source of local feed ingredient for use in tilapia feeds comes from the poultry industry. As mentioned earlier, Malaysia

has a large poultry farming industry with a sizeable number of integrated poultry farming operations. Some of the larger poultry farms have their own feed mills and processing plants. There is currently a great demand for dead chickens and their discarded body parts and offal by small- and medium-scale freshwater fish farmers. Agreements are usually brokered between fish farmers and nearby poultry processors to ensure a ready supply for the farm. As previously described, these chicken waste products are used as supplementary feed inputs (Figures 13 and 15). The dead poultry and their offal are often cooked before being fed directly to farmed fish. However, some farmers do not cook the carcasses but grind them with a meat mincer and, after mixing with flour, feed the processed meat to farmed fish (Figure 19).

FIGURE 19
On-farm grinding of dead chicken carcasses and body parts mixed with flour for use as a feed input in catfish and tilapia farms (left) and poultry by-product meals and poultry fat produced from a local rendering facility (right)

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The high demand for these poultry by-products has resulted in some enterprising larger poultry companies (such as Kentucky Fried Chicken/Ayamas) investing in basic equipment to process them into ground and dried or frozen forms, before packing and selling them to fish farmers at a higher price. A much more hygienic way to utilize these discarded poultry parts is to render them into useful protein meals. However, Malaysia currently does not have an established animal rendering industry. Nevertheless, one company, Dindings Soya & Multifeeds Sdn. Bhd., a subsidiary of Malayan Flour Mills with diversified interests in the feed ingredients, poultry and aquafeed industries, has a small rendering facility in Perak. Discarded poultry parts from their poultry farms are sent to this rendering facility to produce poultry by-product meal (PBM), which is then used in their own aquafeed formulations. They do not produce enough to sell to other aquafeed mills. PBM is known to be an excellent protein source for both fish and shrimp feeds (Bureau, 2006; Yu, 2008). A recent evaluation of locally produced PBM in feeds formulated for a carnivorous marine fish showed excellent growth performance that was equivalent to feeds formulated with PBM sourced from the United States of America or fishmeal (Shapawi, Ng and Mustafa, 2007); this indicates that local technology for rendering is available. Other potential feed ingredients from poultry rendering facilities would include feather meal and poultry fat, which would provide sources of dietary protein and lipid/energy, respectively. Significant quantities of blood meal can also be produced. It is hoped that a coordinated effort can be made by the relevant local authorities to centralize the collection of discarded poultry parts and to set up large rendering facilities to provide high-value feed ingredients for the thriving aquaculture sector. This can be patterned after organized rendering associations, such as those found in the United States of America, Canada and Australia. Currently, much of the rendered animal feed ingredients are imported into the country (Table 6).

These are indeed exciting but challenging times for the aquaculture industry in Malaysia. The rising costs of feed ingredients put aquafeed producers and tilapia farmers constantly at the mercy of market price fluctuations. Even though the global market for tilapia products continues to expand, the price of tilapia has remained stable. Increasing feeding costs and a stagnated market price of tilapia means reduced profit margins for tilapia producers. As indicated by the results of this survey, feeding costs account for about 63 percent of the total production costs of tilapia in Malaysia. Any savings in feeding costs would greatly benefit the tilapia farming industry. The use of locally sourced alternative protein and energy feed ingredients in both commercial and farm-made feeds would go far towards keeping the cost of production sustainable in the long term. Better on-farm feed management and feeding practices could also contribute towards cost savings. Small-scale tilapia farmers in Malaysia are especially vulnerable to rising feed costs and competitive tilapia markets (WFC, 2009). More extension services should be provided to enable these farmers to gain knowledge on producing nutrient-appropriate farm-made feeds using low-cost local feed ingredients. Farmers who use low-cost feed inputs often experience poorer tilapia growth performance; this illustrates the need for education on providing adequate nutrient input and proper feeding practices. It is hoped that this field survey will contribute to the current efforts, both by government and private-sector stakeholders, to make Malaysia a major global tilapia producer.

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Feed management of major carps in India, with special reference to practices adopted in Tamil Nadu

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ABSTRACT

In India, major carps, namely catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus cirrhosus*) dominate aquaculture production. Although Chinese carps such as common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*) and silver carp (*Hypothalmichthys molitrix*) are cultured, their popularity in the market remains low. In some of the emerging commercial culture systems Chinese carps are almost excluded due to marketing and other management constraints. Due to the non-availability of compounded feeds, the majority of farmers in most parts of the country continue to depend on a conventional mixture of rice bran and oil cake as the common supplementary feed. Application of manures and inorganic fertilizers to produce natural food is widely used, even when compounded feeds are employed. With the increased commercialization of carp farming and greater market focus, demonstration of the commercial viability of the use of pelleted feeds is undertaken by feed companies. With a number of innovations made by farmers in evolving suitable culture practices and feeding methods, pelleted feeds are gaining acceptance in some parts of the country. However, although carp farmers desire to use compounded pelleted feeds, due to the highly dispersed nature of carp farms they are confronted with problems in obtaining feeds in small quantities. Faced also with difficulties in obtaining compounded feeds at an affordable cost, farmers have no option but to continue to use rice bran as the major feed input along with oil cakes, even in states like Andhra Pradesh where carp culture is well organized. In Punjab, where a feed manufacturing factory is located, a competitive pricing policy exists; an effective marketing strategy has been adopted by the company and a high percentage of farmers have switched to the use of pelleted feed. In Tamil Nadu, another state where carp farming has gained popularity, particularly in areas such as Thanjavur District where water is not a major constraint, farmers have begun to realize the benefits of feeding floating pellets. However, availability and delivery to farmers are major constraints hindering the expansion of pellet feed-based carp culture

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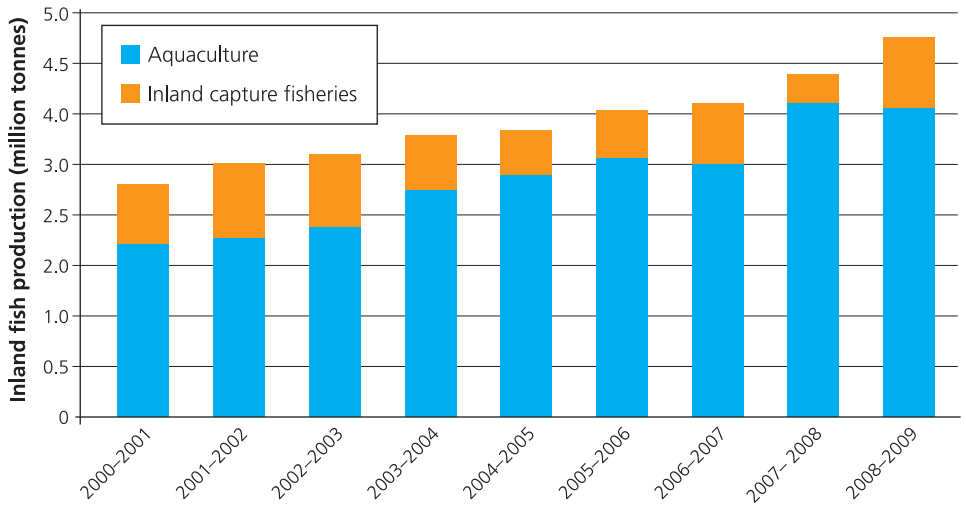
in the state. In this review, an attempt is made to present the general feeding strategies adopted in different parts of India, with a specific case study drawn from the State of Tamil Nadu where farmers have demonstrated the benefits of using floating pellets. The review also covers the current status of feed ingredient availability, the feed manufacturing industries and the strategies that need to be evolved to promote compound feed-based carp culture. A major part of the information used in the preparation of this paper was gathered *via* a country-wide survey on the feeds and feeding practices used in the culture of Indian major carps.

1. AQUACULTURE IN INDIA: CURRENT STATUS AND FUTURE PROJECTIONS

India's freshwater resources consist of rivers and canals (197 024 km), reservoirs (3.15 million ha), ponds and tanks (2.35 million ha), and oxbow lakes and derelict (i.e. ruined and unusable natural waterbodies) waters (1.3 million ha). Carp culture has been promoted in many of these waterbodies for the past four decades. The average fish production from the ponds has been expanded to about 2.5 tonnes/ha/year in several states from an early production level of ~0.5 tonnes/ha/year. However, research results and the accomplishments of progressive farmers indicate the possibility of obtaining ~10 tonnes/ha/year; thus there is good potential to increase present on-farm production levels. To achieve these, feed is recognized as the most important input. As seen in Figure 1, most of the current inland fish production is contributed by the aquaculture sector. By 2007, nearly 50 percent of total national fish production was being contributed by aquaculture (Figure 2), a fact that demonstrates the evolving importance of aquaculture in the current situation of declining capture fishery resources.

FIGURE 1
Inland fish production (million tonnes) in India, 2000–2001 to 2008–2009

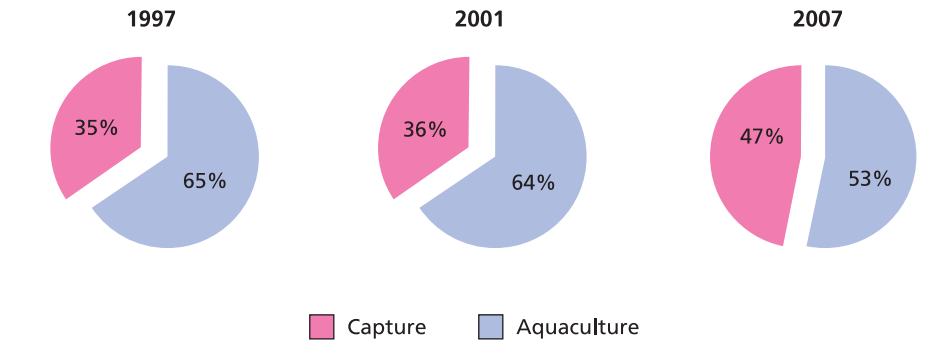


Source: Anon. (2006); data for 2007–2009 courtesy of Paul Pandian, Deputy Commissioner of Fisheries, Planning Commission, Government of India.

In 2006 the combined aquaculture and capture fisheries sectors contributed 1.2 percent to the national gross domestic product (GDP) and 5.3 percent to the national agricultural GDP (FAO, 2008). With a total fish production of 7.13 million tonnes in 2008, the country has become the third largest fish producer in the world.

As mariculture in India is still in its infancy, freshwater aquaculture has been identified as the principal area to cater to the increasing domestic demand for fish. When the entire population of the country is considered, the per capita availability of fish is

FIGURE 2
Changes in the contribution from capture fisheries and aquaculture, 1997–2007



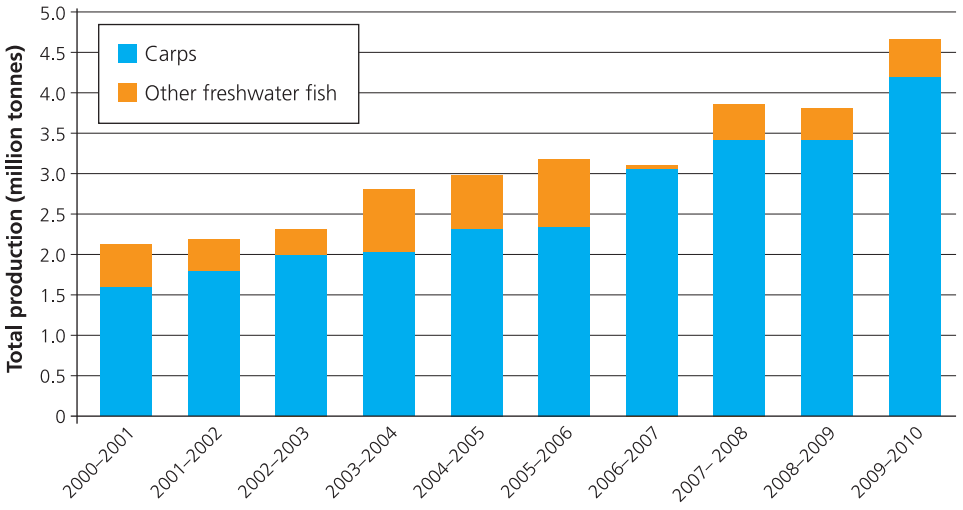
Source: Anon. (2006); FAO (2008).

reported to be only 4 kg. However, as about 65% of the population does not eat fish (due to religious and cultural reasons), it might be assumed that per capita fish availability is more than 11 kg; however the annual per capita fish consumption is only 9.8 kg, which is much lower than the World Health Organization (WHO) recommendation of 13 kg (MFS, 2011). It is projected that the national annual fish requirement will be around 10 and 13 million tonnes by 2012 and 2020, respectively (Eknath, Das and Jena, 2009). With the declining contribution from capture fisheries, much of the production will have to come from aquaculture to fill the deficit. To cope with the increasing demand, it has been projected (Eknath, Das and Jena, 2009) that Indian aquaculture will have to demonstrate an average annual growth rate of over 8 percent in the next five years. An increasing awareness of the health benefits of eating fish will also lead to greater demand.

2. CARP CULTURE IN INDIA

In India, carps are dominant in freshwater aquaculture, and they contribute most of the total cultured fish production (Figure 3). To date, polyculture of Indian major carps and Chinese carps is practiced in fertilized ponds. These fish are fed with a

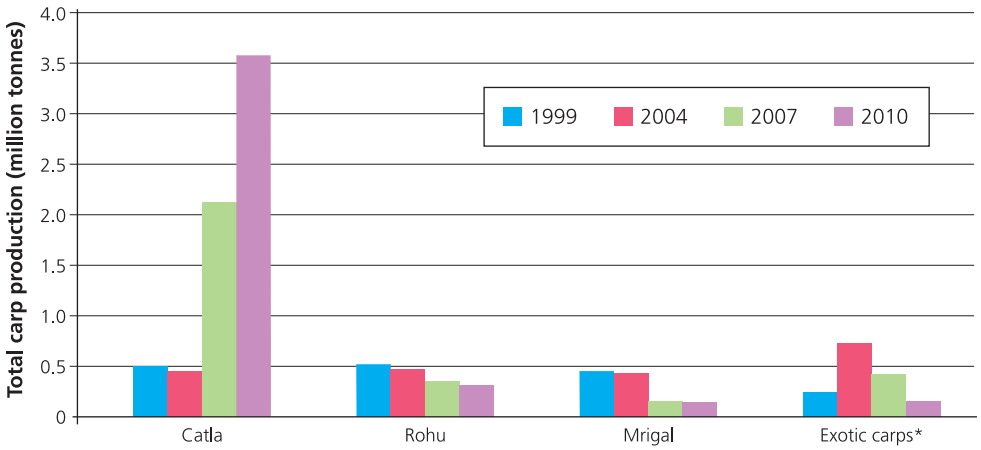
FIGURE 3
Carp production (million tonnes) in India from aquaculture, 2000–2001 to 2009–2010



Source: Anon. (2006); FAO (2012).

supplementary mash feed comprised largely of rice bran and oil cake. The three Indian major carps, namely, catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus cirrhosus*) contribute the majority of the national carp production (Figure 4).

FIGURE 4
Species contribution to total carp production in India (million tonnes)



Note: *Exotic carps include the Chinese major carps (common carp, grass carp and silver carp)
Source: Anon. (2006); FAO (2012); courtesy of Paul Pandian, Deputy Commissioner of Fisheries, Planning Commission, Government of India.

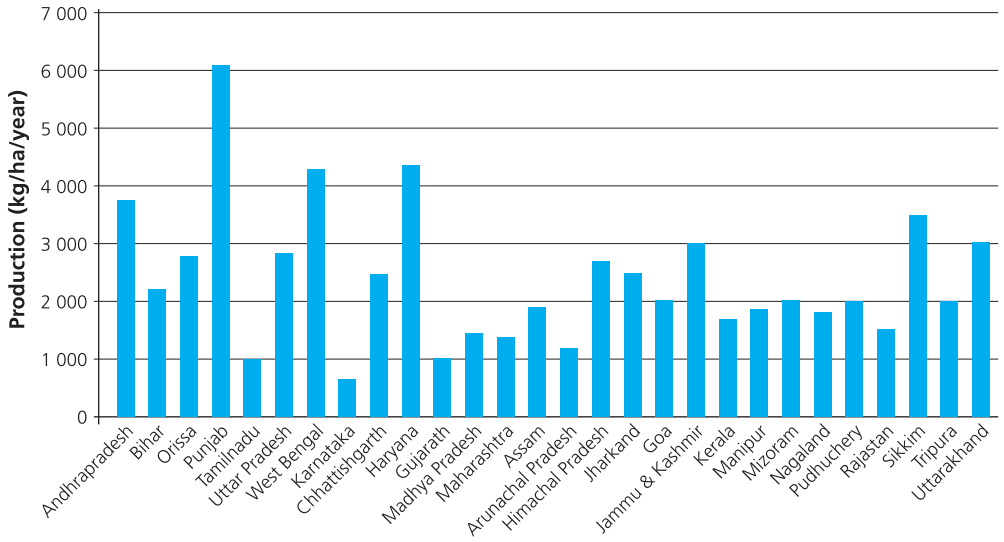
The Indian major carps, with their ability to filter feed by harvesting the natural plankton produced in the system through fertilization, provide the opportunity for low-cost aquaculture systems with reduced risk to farmers. Recognizing this potential, the Government of India has established fish farmers development agencies (FFDA) in almost all possible districts of every state, and provided special support to promote carp farming. Although carp culture now takes place in most states, it has particularly become a commercially significant venture in Andhra Pradesh, Punjab, West Bengal and Tamil Nadu. The species composition of the carps cultured and the farming methods used vary in different parts of the country. Carps are mainly cultured in earthen ponds; these are considered semi-intensive culture units. On the other hand they are also cultured in extensive systems, in large ponds and reservoirs; here the only intervention is to stock fish seed, the fish being allowed to harvest the natural food produced through inherent fertility. Chinese carp culture has also become successful in the colder parts of the country, particularly in northern and eastern India, which are close to mountainous regions.

A three-tiered carp culture system is practiced in India, namely, nursery, rearing and grow-out production systems. Depending on the management strategies that have been adopted, fish production of 1–10 tonnes/ha/year is obtained in different regions, with some progressive farmers recording up to 16 tonnes/ha/year. Small farmers, who constitute the bulk of the fish-farming population, are not able to follow all the package of practices, and their production remains <3 tonnes/ha/year. Many small farmers procure small-sized fish seed instead of fingerlings and stock them in poorly prepared ponds. Failure to follow recommended pre-stocking, stocking and post-stocking management procedures has been limiting production in many of the states. The data compiled by the Government of India (based on the input provided from each state) demonstrate that Punjab, Haryana, Andhra Pradesh and West Bengal have higher per hectare productivity than other states (Figure 5). In Tamil Nadu, although per hectare productivity for the state as a whole is low, higher production is noticed in some areas where feed is included as an integral part of the culture system. The productivity level

observed and the availability of feed ingredients reported in each state is linked; hence any intervention must aim at increasing the availability of feed to farmers in other states.

Survey results indicate that farmers use nine major ingredients and five feed types. The major ingredients are rice bran, groundnut oil cake, cottonseed meal, sunflower meal, soybean meal, mustard oil cake, wheat bran, common salt and mineral mixture. The feed types used are rice bran alone, rice bran and cottonseed meal, rice bran and groundnut oil cake, rice bran and sunflower meal, and rice bran and mustard oil cake. In addition, farmers in some areas also prepare feed mixtures using a variety of locally available resources, including fishmeal and/or locally available low-value and trash fish.

FIGURE 5
Productivity of freshwater fish farming in the states of India (kg/ha/year), 2008–2009



Note: Data presented pertain only to the productivity from the Fish Farmers Development Agency (FFDA) ponds.
Source: Data courtesy of Paul Pandian, Deputy Commissioner of Fisheries, Planning Commission, Government of India.

2.1 Species combinations

Carp farming in India is undergoing major changes that are related mainly to market focus. The traditionally recommended six-species composite carp culture system has not been successful from an economic point of view, even though a higher level of productivity is obtained. Several strategies for carp culture have thus evolved in the country to suit the market requirements and the availability of water resources, fertilizers, feeds, etc. and the investment capability of farmers.

Market demand for rohu is the highest, and this species is preferred in most parts of the country. Catla is also a preferred species in the carp farming community, owing to its fast-growing nature; hence in Andhra Pradesh it is stocked with rohu at about 10–20 percent and cultured in commercial systems. Along with these two species, 5–10 percent mrigal is also stocked as a scavenger to consume the food available at the pond bottom.

In other areas of the country, stocking densities for catla and mrigal are increased, with rohu being stocked at around 40–50 percent. Unlike Andhra Pradesh where the stocking percentages for rohu, catla and mrigal are strictly regulated, the availability of seed in other areas influences the species stocking composition and density. In addition to Indian carps, Chinese carps such as grass carp and common carp are added, with least preference given to silver carp. Also, polyculture of carps and giant river prawns (*Macrobrachium rosenbergii*) is practiced by some farmers in Andhra Pradesh, as well as in West Bengal. The culture of striped catfish (*Pangasianodon hypophthalmus*) with carps is gaining popularity in Andhra Pradesh and a few other parts of the country.

The stocking density adopted by farmers varies widely in different parts of the country, but progressive farmers generally restrict stocking density to less than 10 000/ha. Some farmers who use small fish seed employ higher stocking densities (up to 20 000/ha). In commercial systems the stocking density is highly regulated, and based on the final weight targeted. Also, the size of the seed stocked has a tremendous influence on growth and production; Table 1 presents an example from the study carried out in Tamil Nadu. Farmers stock small fish, whose survival depends on the care taken in pond preparation (i.e. removal of predators and other fish that compete with these species for food and space). As can be seen from Table 1, farmers stock six major carp species (however, the proportions stocked are not available). Generally the progressive farmers, who decide on stocking density based on market demand, tend to stock a larger percentage of rohu. Farmers using floating feed stock larger, stunted fingerlings/yearlings (see Section 2.4) with the objective of harvesting fish within about six months, when they will have attained a marketable weight of about 500 g.

The technology for stocking larger fish seed has yet to become a reality in most parts of the country. As the breeding of carps is still limited to the monsoon season, constraints in rearing space have compelled producers to sell smaller seed; the buyers, who are unaware of the benefits of stocking larger seed, have resorted to stocking with available seed - irrespective of the size. However, this trend is changing with the increasing spread of information on the benefits derived by the farmers in Andhra Pradesh. An important strategy that needs to be adopted to increase carp production is to stock larger seed at appropriate densities.

TABLE 1
Stocking practices adopted in carp culture systems in Thanjavur District, Tamil Nadu

	Conventional[1]	Floating Pellet	Mash + sinking pellet	Overall
No. stocked/ha	6 067±156	6 929±185	5 896±2 496	4 670±2 573
Species stocked		***Number of farmers***		
Catla	15	15	15	45
Rohu	15	15	15	45
Mrigal	15	15	15	45
Silver carp	9	4	1	14
Grass carp	9	3	7	19
Common carp	6	8	5	19
Size stocked (g)	**5**	**50–100**	**5–10**	**–**

Note: Generally 60 percent of the stock was rohu, with the rest being distributed mainly among the two other Indian carps and a very small percentage of Chinese carps.

Source: Field survey (2010).

2.2 Pond preparation and fertilization for live feed generation

Lime is commonly used by farmers and is applied at 200–300 kg/ha as an initial dose, irrespective of the pH level. This is followed by the application of cow dung (the most common animal manure used) by most farmers at an initial dosage of 2 000–3 000 kg/ha. In addition to cow dung, inorganic fertilizers such as urea and superphosphate are also commonly used. Organic compost (Figure 6) is used by some farmers to improve plankton productivity. Following the initial dose and after stocking the seed, farmers in most parts of the country resort to regular fertilization with organic manures and inorganic fertilizers. The amounts used are based on the fertility level of the water, which is estimated by visual observation coupled with the

experience of the farmer. The application of organic manures (Figure 7) can be up to 20 tonnes per ha, or more in the case of farmers in Andhra Pradesh; coupled with a higher level of application of inorganic fertilizers such as urea and superphosphate, the combined level of all the inorganic fertilizers used could be more than 1 000 kg/ha. Farmers in Andhra Pradesh have developed these application levels based on practical experience, and thus studies are needed to ascertain the impact of these fertilizers on fish growth (such studies can help to determine the optimal level of fertilization and reduce nutrient input costs).

A summary of the variety of levels of organic manures and inorganic fertilizers applied during the different stages of carp culture in various parts of the country is given in Table 2. The practices adopted vary widely and thus this information can only be used as indicative data to conduct trials in specific areas and develop technologies appropriate to the locations. The use of fertilizers in reducing risk to farmers and increasing productivity is an important factor to be considered, and emphasis should be placed on making farmers aware of the advantages of the use of formulated pelleted feeds. Feed companies also need to explore the ability of carps to harvest natural food that is rich in micronutrients essential for fish health and growth. Such an approach would reduce feed costs, help farmers derive greater benefits from the system and contribute to reducing nutrient discharge to the environment.

FIGURE 6
Compost pit

Courtesy of P. Antony Jesu Prabhu

FIGURE 7
Organic manure application

Courtesy of P. Antony Jesu Prabhu

TABLE 2

Fertilization schedule for different types of carp culture ponds

Type of pond & stocking density	Type of fertilizer	Rate of application	Frequency
Nursery pond 6.25 million /ha for 2 weeks	***Organic manure***		
	Cow dung	5 000 to 15 000 kg/ha	In one instalment at least 14–15 days before stocking
	Spaced manure application		
	Cow dung	10 000 kg/ha	15 days prior to stocking
		5 000 kg/ha	7 days after stocking
		5 500 kg/ha	Immediately after removal of the first crop, when more than one crop is raised
	Mustard oil cake + cow dung + poultry manure at 6:3:1	1 000 ppm for the culture of zooplankton for carp spawn	
	Inorganic fertilizer		
	N:P 4:1		
	N:P:K 8:4:2		Weekly
	N:P:K 18:8:4	500 kg/ha	After liming at 200 kg/ha
	Both		
	Mustard oil cake + 6:8:4 N:P:K	On equivalent nutrient basis at 12 kg N/ha	
Rearing pond 200 000 to 300 000/ha	***Organic manure***		
	Cow dung	3–7 tonnes/ha	In rearing ponds, 50% of the total requirement is applied 15–20 days prior to stocking of fry and the remainder in two equal monthly applications during the rearing period
	or	*or*	
	Biogas slurry	5.5–12 tonnes/ha	
	and	*and*	
	Cow dung	2.5–5 tonnes/ha	
	or	*or*	
	Biogas slurry	10–30 tonnes/ha	
	or	or	
	Poultry dropping	5–15 tonnes/ha	
Rearing pond	***Inorganic fertilizers***		
	Urea	108–152 kg/ha	Should be applied in equal monthly applications alternately with organic manure with a gap of about 2 weeks
	Calcium ammonium nitrate	200–280 kg/ha	
	Ammonium sulphate	250–380 kg/ha	
	Single superphosphate	156–312 kg/ha	Weekly; first instalment is given 7 days after initial organic manure application in equal monthly applications
	Murate of potash	16–32 kg/ha	
	or Sulphate of potash	20–40 kg/ha	
Stocking pond	***Inorganic fertilizers***		
	Urea	163–326 kg/ha	
	Calcium ammonium nitrate	300–600 kg/ha	
	Ammonium sulphate	375–750 kg/ha	
	Single superphosphate	250–468 kg/ha	
	Murate of potash	41–66 kg/ha	
	or		
	Sulphate of potash	52–83 g/ha/year	

Source: Reproduced from Ray (2013).

In the study area of Tamil Nadu, farmers have been using fertilizers at various levels depending on the quality of supplementary feed used (Table 3). In general, the use of lime, organic manures and inorganic fertilizers declines when farmers use pelleted feed. The amount of lime used by conventional farmers (463 kg/ha) and the sinking-pellet farmers (474 kg/ha) was almost equal, while the farmers using floating pellets used only a small amount (127 kg/ha). The use of organic manures and inorganic fertilizers was higher in the case of the conventional system as compared to the other two systems. Interestingly, farmers using floating or sinking pellets used other organic inputs such as Zymac (brand name of a commercially available biofertilizer applied to increase plankton production). Pond preparation is completed by July or August and thereafter, stocking with fingerlings or stunted fish seed is undertaken.

TABLE 3

Input usage (kg/ha) patterns observed in the different feed-based systems in Tamil Nadu

Parameter	Conventional	Floating pellet	Mash + sinking pellet	Overall
Cow dung	6 119±3 820	4 623±2 573	3 557±3 079	4 766±2 840
Urea	145±61	3.5±10.2	60.8±57.4	70±50
Super phosphate	147±70	4.3±45.9	50.5±67.2	67±53
Zymac	–	1.52±2.81	5±7	2.2±5.5
Feed	5 915±2 940	5 084±643	3 505±1 329.3	4 835±1 303
Feed conversion ratio (FCR)	1.96:1	1.11:1	1.26:1	1.44:1
Feed type	Rice bran/oil cake mix	Uno	Gold Mohur, CP	–
Lime	463±320	127±109	474±613	348±77

Source: Field survey (2010).

2.3 Feed conversion ratios (FCR)

The best FCR is obtained through the judicious use of feed and the production of natural food through fertilization. Among the three types of feed used in Tamil Nadu, the best FCR (1.1:1) was obtained by floating pellets (Table 3). Regulation of feed ration based on the actual feed consumption pattern helped farmers to minimize feed wastage. Furthermore, the higher stability of floating pellets ensured their nutritional quality without much loss due to leaching, even in cases where their consumption was delayed.

The lowest FCR (1.96:1) was observed when conventional feeding practices were used, reflecting the higher wastage of feed as well as the low nutrient availability of the feed used. Although carps are known to browse the feed through the holes in the feeding bags, there appears to be more feed wastage than in the case of conventional feeds.

In contrast, the feeding of pellets provided a slightly better FCR (1.26:1). As the ponds are also fertilized, these FCR values reflect the combined effect of feed and the natural food produced through fertilization.

2.4 Increasing natural food production through the use of substrates

Although pelleted feeds are gaining increasing acceptance, farmers hold a strong belief that the production and use of live food will help to improve the quality of fish and the profitability. Farmers have started to adopt techniques to develop the periphyton community in the ponds, such as fixing bamboo poles, installing coconut leaves, hanging sugarcane baggase in the pond, etc. (Figure 8). These organic substrates are known to increase the availability of periphyton and other food organisms. The results of such research have demonstrated the great potential of this technique in increasing the production of carps, particularly of species like rohu (Shankar, Mohan and Nandeesha, 1998; Mridhala *et al.*, 2005). Testing the commercial-scale application and viability of these techniques may have great benefits for farmers, as there is enormous demand for species like rohu.

FIGURE 8
Periphyton generation in ponds using various substrates and the measurement of productivity
Top left: coconut leaves; top right: bamboo poles; bottom left: sugarcane baggase; bottom right: plankton estimation

COURTESY OF P. ANTONY JESU PRABHU, M.C. NANDEESHA AND K.M. SHANKAR.

The addition of organic manures and inorganic fertilizers helps to improve natural food availability. The quality of the natural food produced will also influence feed conversion ratios (FCR), as is evident from the small number of samples studied in Tamil Nadu comprising three different systems.

2.5 Stocking size

In most of the country, the stocking of undersized fish seed continues to be a major hurdle to increasing fish production. Although a huge amount of carp seed is easily produced by employing the Chinese and/or 'jar' hatchery systems, the survival from spawn to fry stage is mostly still less than 20 percent. The fry are then reared to fingerling size if there is enough space, or else they are used for stocking once they reach 3–4 cm. However, the percentage surviving from this small size to adult fish is very low, particularly when the waterbodies are infested with predators and water quality is poor.

The concept of stunted yearling production and stocking in grow-out ponds was developed and propagated by the fish farmers of Andhra Pradesh and is gradually spreading to other parts of India. Farmers stunt fingerlings for a period of 6–12 months by maintaining them at high stocking densities and feeding at a rate of 2–3 percent body weight, a level sufficient for survival and some growth (Figure 9). The stocking density used in such ponds can vary from 50 000 to 100 000/ha. On average, the stunted yearlings reach a size of 100–150 g. When stocked in production ponds at normal density levels and given adequate food, these stunted yearlings rapidly gain additional weight, reaching a marketable size of 700–1 000 g in 6–8 months.

Once nutritional restriction (or under-nutrition) is removed, the favourable conditions in the grow-out ponds invoke a number of compensatory responses, including hyperphagia, rapid weight gain and better feed conversion efficiency as compared to that seen in continuously fed (normal) fish. Farmers thus take advantage of this compensatory or 'catch-up' growth phenomenon that occurs following a period of food deprivation. Although the production of stunted fingerlings involves a delay of one year, this loss of time is compensated by the production of a greater number of yearlings due to high stocking density, higher growth rate in the production ponds and a subsequent reduction in the culture period and feed costs. Survival rates are also high, as the stunting process eliminates the weaklings.

FIGURE 9
Stunted yearlings

COURTESY OF A. SUDHAGAR.

Farmers in Andhra Pradesh have further improved this stunting technology through stocking density management. They produce fish of larger weight (up to 500 g) by the stunting process; these are called 'zero class' fish. When thinned and stocked in grow-out ponds, these fish attain market size in 5–6 months. When there is an assured water supply, farmers using this process can easily raise two crops of fish per year.

2.6 Nutrition and feeding

Extension support to farmers and the entry of entrepreneurs into carp aquaculture have helped to realize the optimal production level in a significant number of farms. However, a much greater number of small farmers that are spread throughout the country have not yet been able to harness the technological progress, either due to difficulties in obtaining feed or to socio-economic reasons. Many of the carp farmers of Andhra Pradesh, Punjab, West Bengal and Tamil Nadu have realized the importance and benefits of the use of pelleted feeds in carp culture and have been able to obtain good production. The transition of the carp farmers from traditional mash feed to pelleted feeds is discussed later in this review.

3. FEEDING PRACTICES

3.1 Conventional feeding practices and their limitations

India is reported to produce nearly three million tonnes of carps annually (Anon, 2006). Most of this production is based on the use of a farm-made mash of raw ingredients. The farm-made mash feed is comprised of rice bran and oil cake (groundnut, mustard and cottonseed cakes are widely used), typically in the ratio of 50:50. However, nowadays 80 (or even 90) rice bran: 20 (10) oil cake is popularly used in the kolleru

regions of Andhra Pradesh. This conventional method of feeding costs US$ 0.1–0.2 per kilogram of fish produced (Suresh, 2007), which is much less than the US$ 0.4–0.6 per kilogram that it costs with commercial pelleted feeds. However, the use of this conventional feed mixture, or no feed at all, contributes to the poor growth of fish as compared to that achieved by pellet-based carp farming. Some of the main limitations encountered in the use of farm-mixed conventional supplemented feeds are:

- The procuring and storing of large quantities of raw ingredients requires good infrastructural facilities that are not available to small- and medium-scale carp farmers. In such cases, farmers are subjected to seasonal fluctuations in the availability and market price of the required ingredients. Even large farmers who can procure and stock these ingredients in bulk when the market price is low are confronted with storage-related quality issues.
- Most importantly, the nutrients in the mash feed mixture are sometimes placed in perforated bags that are suspended in the pond water column; these leach into the water very quickly. It appears that a portion of the ration is not eaten by the fish, instead serving to fertilize the pond.
- The nutrient load that is delivered into the pond soil and water through the use of these conventional feed mixtures can lead to production problems and also poses a potential danger to the natural ecosystem through eutrophication, a prime environmental concern.
- The poor FCR (3:1–4:1) of these conventional mash feeds, due to rapid nutrient leaching and poor water stability, cannot support the intensification, expansion and further development of carp culture in India.

3.2 Unconventional feeding strategies

Certain progressive fish farmers, mainly from the states of Andhra Pradesh, West Bengal, Punjab, Haryana and Tamil Nadu, have evolved and adopted some unique practices in seed production, nursery rearing, grow-out culture, feeding and - to some extent - marketing. The feeding strategies that have been adopted play an important role in maximizing nutrient availability and can determine the success of a culture operation. Specifically defined feeding strategies have been adopted to minimize feed wastage and nutrient loss by leaching and to maximize growth. Andhra Pradesh remains a pioneering state in Indian aquaculture because of the innovative thinking and experimental ability of its fish farmers, who have developed their own successful feeding strategies that have contributed to boosting aquaculture production in the country. The feeding strategies employed are outlined below.

3.2.1 "Stop feeding"

These farmers employ the simple feed management practice of not feeding the fish at regular intervals. Generally, the fish are not fed one day in every ten; this allows the farmers to eliminate the cost of feeding for that particular day and ultimately reduces the cost of production significantly. This practice of 'stop feeding' is well supported scientifically by the fact that starvation and subsequent feeding enhances feed intake and improves growth rate through compensatory growth mechanisms.

3.2.2 "Break feeding"

One of the basic principles in feed management is that an increase in the feeding frequency will lead to a uniform size of the population. When the total feed ration per meal is applied at a single time, the larger fish or 'shooters' dominate and consume most of the feed, and the relatively smaller fish get only the leftovers. This leads to unequal fish size at harvest, which affects market price. To solve this problem, farmers using pelleted feed have devised an approach known as 'break feeding', in which the ration for each meal is split into two portions and applied at an interval of 20–30 minutes.

The dominant fish are fed to satiation by the first portion of the ration and the smaller fish get to feed to satiation on the second portion. This has helped to minimize size variation at harvest. However, in this case farmers do not use bags for feeding but apply pellets to the water at fixed times every day.

3.2.3 "Bag feeding"

Fish fed to satiation through demand feeding show higher weight and protein gain. This principle is effectively exploited by these fish farmers, based on their experiences and observations. Mainly for carps, farmers practice a different type of feeding method termed 'bag feeding', in which perforated bags are filled with the mash of feed ingredients or the sinking pellets and suspended in the water column by tying them to bamboo poles (Figure 10). The fish feed to satiation by nibbling through the holes in the bag. The feed bags are removed and dried before re-use.

FIGURE 10
Feeding bags in pond

COURTESY OF B.S. KAMALAM.

3.2.4 Feeding enclosures

A feeding enclosure is a small area in the centre of the pond, which is enclosed on all sides by netting that extends one foot above and one foot below the surface of the water and is fixed in place by bamboo poles. Floating feed pellets are broadcast inside this netting enclosure. In this way, the feed is made easily accessible to the fish in a specific area where they can aggregate and feed, thus preventing wastage (Figure 11).

FIGURE 11
Feeding enclosure

COURTESY OF B.S. KAMALAM.

3.2.5 Gelatinization

Gelatinization is a process by which the bound starch granules in some plant-based feed ingredients are converted into an easily digestible and more bio-available form by means of cooking. Some of the fish farmers in Andhra Pradesh cook broken rice and feed it to their fish as a mash mixture, based on their experience that cooking improves digestibility and thereby enhances growth. However, this method of cooking is not generally practiced for carps, but is used mainly in the case of catfish production.

4. COMPOUNDED PELLETED FEEDS FOR CARPS

The conventional feeding practices used in India have gradually been transformed with the commercialization of carp culture and the entry of commercial feed manufacturers.

4.1 Sinking pellets

Sinking pellets possess better water stability, compared to mash feed, but that stability depends on the ingredient composition and the method of processing. This type of feeds are manufactured commercially for carps by a few feed mills with the incorporation of various plant-based feed ingredients (fishmeal is generally not included or is included only at a low percentage) and other nutritional supplements such as a vitamin and mineral premix. The size of the pellets used in the grow-out system varies widely, the diameter ranging from 2.3 to 3.2 mm and the length from 8 to 12 mm. The feed is heat processed by steam, which increases stability, reduces microbial load and improves nutrient digestibility and palatability.

However, the use of sinking pelleted feeds for carps also has some limitations. The pellets cannot be broadcast freely on the pond surface, as they sink to the pond bottom because of their high density, making the feed less available to fish. Hence sinking pellets are generally given using the bag feeding method; however, due to the use of this method the actual amount of feed eaten by the fish is difficult to assess (Sahu and Saravanan, 2009). The FCR (2:1) of the sinking pelleted feed for carps is much better than that of the conventional feed mixture, which is a mixture of either rice bran/de-oiled rice bran and oil cake (groundnut oil cake/mustard oil cake) in the ratio of 1:1 to 4:1 (the ratio varies with local availability of ingredients, price fluctuations and the preferences of individual farmers). In Punjab, sinking pellets have gained popularity because of the promotional efforts of the feed companies. Although the growth is not substantially different to that achieved with the conventional mixture, farmers have begun to adopt pellets because of their convenience (Debnath *et al.*, 2007). This not only helps to reduce feed costs, which account for 50–60 percent of the operating costs in any aquaculture venture, but also helps to reduce the environmental impacts by minimizing feed wastage.

4.2 Floating pellets

The processing of feed ingredients by extrusion not only helps in the production of hard sinking pellets but can also be used to produce pellets with very low density such that they can float on the water surface for a period of time (20–30 min). As with most advanced technologies, the cost of production per unit of floating pellets is higher than that of sinking pellets. However, floating pellets have a range of advantages over sinking pellets, including: better FCR (1.2:1–1.5:1); reduced feed wastage; easier feed management (including regulation of feed ration through direct observation); easier accessibility to fish; easier removal of unconsumed feed to prevent environmental degradation; and less labour requirements. In addition, the use of floating pellets increases production per unit area by improving the growth rate achieved through the use of mash feeds and sinking pellets. This is evident from the results of the study carried out in Tamil Nadu, where preliminary comparisons, based on actual practice were made (see Sections 9 and 10). Although more extensive studies are needed to draw definite conclusions, the results are indicative of the larger benefits that can be obtained by using floating pellets.

5. FEED DISPENSING METHODS

In addition to the nutritional composition of the diet, importance must be given to the methods used by farmers to present feed to the fish. A wide range of feed-dispensing practices are used by carp farmers in India. These vary from region to region, and even from farmer to farmer within the same region. Some of the feeding methods followed by the Indian carp farmers are:

- baskets tied to poles installed in the pond and kept immersed in the water column (Figure 12);
- perforated bags tied on a rope and immersed in ponds to a depth of 1 foot from the bottom (Figure 13);
- polythene bags tied horizontally in the corners between four poles and made like a tray; and
- a pen-like structure created with the help of poles and fishing net, with a bottom opening.

The success of Andhra Pradesh farmers in bag feeding has influenced many farmers from other regions to adopt this method. While the above types of feed-dispensing methods are adopted by progressive farmers, a large majority of farmers follows the method of spreading the feed in fixed spots of the pond. This feeding practice results in considerable wastage of feed, the feed mostly serving as manure.

FIGURE 12
Basket feeding

COURTESY OF J.K. JENA.

FIGURE 13
Bag feeding

COURTESY OF J.K. JENA.

6. PROMOTING PELLET-FED CARP CULTURE IN INDIA

Considering the fact that mariculture is still in its infancy in India, the best option is to focus on increasing production from the national freshwater sector. Alternative species, such as tilapia and striped catfish, are viable additional species that can be promoted together with carps; however, farmers are likely to continue to depend on Indian major carps and Chinese carps (particularly common carp and grass carp) in many localities. While the culture success of tilapia and catfish would largely depend on the availability of seed and pelleted feed, Indian major carps can continue to thrive on natural production enhanced by fertilizers coupled with the use of conventional feed mixtures.

Most of the Indian carp farmers who have been taught feed-based fish farming through demonstrations and seminars have accepted the new technology and have started using formulated fish feeds. Godrej Agrovet (P) Ltd., which has a special division for the production of livestock and fish feeds, has taken a major initiative to promote feed-based carp farming in Punjab and Andhra Pradesh. This company has been

successful in encouraging a majority of farmers in Punjab by providing competitively priced feed, a practice that helps farmers to buy compounded feed, rather than feed ingredients for on-farm use. However, the success of such companies in promoting pelleted feed for carp culture in India, where the bulk of the fish is produced through semi-intensive culture, is still limited by various constraints. For marketing, most of the fish produced in Andhra Pradesh have to be transported to various parts of the country, particularly to eastern India. Hence, the additional transportation costs and the relatively low farm-gate price offered by buyers in Andhra Pradesh have discouraged farmers from venturing into the use of pelleted feeds, and they continue to rely on rice bran mixed with oil cake in their production systems. In contrast, in Punjab and Tamil Nadu much of the harvested fish is marketed locally or at best transported to nearby markets in other states; thus farmers can make a profit by using quality pelleted feed.

The responses from the farmers (see Sections 9 and 10) on the benefits of using pelleted feed highlight increased productivity, reduced grow-out time, ease of operation, good fish health caused by better water quality, etc. A few of the progressive farmers from Tamil Nadu have been experimenting with the use of floating pellets in carp culture for the past four to five years with positive results. With the establishment of floating pelleted feed companies and the increased availability of pelleted feed, the number of farmers switching to floating pellets should increase. A progressive farmer has established a small floating feed manufacturing unit to cater to his needs. The promotion of such small-scale production units as a business model may help farmers locally. By ensuring an adequate supply of quality feed ingredients, such small-scale feed plants have the opportunity to succeed.

7. FEED INGREDIENT AVAILABILITY

Due to India having an agrarian economy, a variety of agricultural resources are available for use in animal feeds. The estimated production of primary agricultural commodities that provide a significant amount of by-products, which can be used in fish feed, is presented in Table 4, while the chemical composition of the commonly used feed ingredients is given in Table 5. There is heavy competition for several of the agricultural by-products from the poultry and other animal husbandry sectors, which have well-established markets for their produce. Although estimates indicate that the agricultural by-products available nationally are adequate to meet the expected demand for feed ingredients, there is an urgent need to make feeds and fertilizers available in individual states and to develop strategies to increase the availability and distribution channels for them to aquaculture feed industry establishments (Ayyappan and Ali, 2007; Suresh, 2007).

TABLE 4

Estimated production of primary agricultural commodities in India, 2007–2008

Commodity[1]	Quantity (million tonnes)
Pearl millet (bajra)	9.79
Sorghum (jowar)	7.78
Corn (maize)	19.30
Oilseeds	28.83
Rice	96.43
Wheat	78.40
Groundnut	9.36
Rapeseed & mustard	5.80
Sunflower	1.44
Soybean	9.99

Note: [1]Vernacular names commonly used in India are given in parentheses.

Source: Anon. (2009).

TABLE 5

List of commonly used feed ingredients used in carp culture[1]

Feed ingredients	Nutrient composition (% on dry matter basis)					
	Moisture	Crude protein	Crude lipid	Ash	Gross energy (kJ/g)	Price per tonne (US$)
Ingredients of animal origin						
Fishmeal	8–10	45–65	8–12	20–40	14.94	611.1
Shrimp waste	10–15	22–34	2–7	10–20	n.s.	n.s.
Squilla meal	10–14	40–46	1–3	12–18	12.62	n.s.
Squid meal	8–12	70–75	4–8	3–5	n.s.	n.s.
Clam meal	8–10	48–50	8–11	4–6	n.s.	n.s.
Silkworm pupae	8–10	40–45	15–25	12–15	28.88	n.s.
De-oiled silkworm pupae	8–10	60–70	2–5	6–7	n.s.	n.s.
Blood meal	10–15	85–90	1–2	2–4	83.72	n.s.
Meat meal	8–10	50–70	4–9	10–15	70.32	n.s.
Liver meal	7	65	3.4	2.4	n.s.	n.s.
Earthworms	5	51.7	3.4	12.5	n.s.	n.s.
Ingredients of plant origin						
Groundnut oil cake	7–10	40–43	4–8	8–10	19.53	175.9
Soybean meal	8–10	50–55	1–2	5–6	19.08	296.3
Broken rice	7–10	12–16	12–14	5–8	14.75	129.6
Rice polish	8–12	12–18	12–14	5–8	19.21	101.9
De-oiled rice bran	8–10	15–18	1–2	8–12	10.11	133.3
Rapeseed cake	11–12	32–38	5–7	6–7	n.s.	174.1
Salseed cake	8–10	7–8	3–4	10–12	n.s.	n.s.
Sesame oil cake	7–10	35–42	3–6	10–13	19.61	n.s.
Mustard oil cake	8–10	25–38	6–9	10–12	19.57	n.s.
Cotton seed cake	7–10	32–35	6–8	8–12	19.74	89.3
Sunflower oil cake	10–12	30–32	4–8	8–10	14.21	92.6
Maize flour	10–12	5–6	3–4	2–3	13.92	111.1
Barley grain	10–12	8–10	2–3	2–3	n.s.	n.s.
Wheat bran	9.3	12.6	7.5	4.2	18.82	92.6
Wheat flour	10–15	8–11	2–4	1–3	18.79	194.4
Tapioca flour	10–12	3–6	2–3	2–3	16.45	n.s.
Spirogyra powder	44.5	8.1	2.8	5.95	6.28	n.s.
Sorghum	10	9	2.8	0.1	n.s.	92.6
Spirulina powder	8.47	54.5	1.1	11.53	20.12	n.s.
Water hyacinth meal	3.3	19.5	2.3	9.3	16.87	n.s.
Pistia meal	4.9	19.5	1.3	25.6	n.s.	n.s.
Leucaena meal	11.8	33.1	4.7	7.2	n.s.	n.s.
Salvinia meal	2.6	16.2	1.1	22	n.s.	n.s.

Note: n.s. = not stated.

Source: Jafri *et al.* (1992); Erfanullah and Jafri (1998); Nandeesha *et al*. (2000); Anon. (2006); Suresh (2007).

7.1 Relationship between fish production and feed ingredient availability

Analysis of the trends in the state-wise production of primary agricultural commodities and in the state-wise aquaculture or carp-culture production shows that those states that are the major producers of agricultural commodities have also established themselves as major producers of aquaculture commodities (Table 6). This clearly shows that feed ingredient and feed availability play a pivotal role in the development of freshwater aquaculture, mainly the carp-farming sector of India.

TABLE 6

Top Indian states in the production of agricultural commodities of aquafeed importance, together with the top inland fish and Indian major carp producing states

Crop	Top 3 state producers	Production (million tonnes)	% share		
Food grains					
Rice	West Bengal	14.75	15.80	**Top ten states in inland fish production (thousand tonnes)**	
	Andhra Pradesh	11.87	12.72		
	Uttar Pradesh	11.12	11.91		
Wheat	Uttar Pradesh	25.03	33.02	West Bengal	1 020
	Punjab	14.60	19.26	Andhra Pradesh	673
	Haryana	10.06	13.27	Uttar Pradesh	290
Maize	Karnataka	2.72	18.01	Bihar	280
	Andhra Pradesh	2.46	16.29	Orissa	203
	Bihar	1.71	11.32	Assam	188
Total food grains	Uttar Pradesh	41.21	18.97	Tamil Nadu	155
	Punjab	25.31	11.65	Maharashtra	135
	Andhra Pradesh	16.23	7.47	Chhattisgarh	132
Oil seeds				Karnataka	121
Groundnut	Gujarat	1.44	29.63	**Top five states in Indian major carp production (thousand tonnes)**	
	Tamil Nadu	1.01	20.78		
	Andhra Pradesh	0.74	15.23		
Rapeseed & mustard	Rajasthan	3.81	51.21		
	Uttar Pradesh	0.87	11.69	West Bengal	790
	Haryana	0.80	10.75	Andhra Pradesh	377
Soybean	Madhya Pradesh	4.78	54.01	Uttar Pradesh	291
	Maharashtra	2.89	32.66	Bihar	111
	Rajasthan	0.77	8.70	Punjab	102
Sunflower	Karnataka	0.52	42.28		
	Andhra Pradesh	0.33	26.83		
	Maharashtra	0.20	16.26		
Total oil seeds	Madhya Pradesh	5.81	23.92		
	Rajasthan	5.17	21.28		
	Maharashtra	3.72	15.31		

Source: Anon. (2006, 2009).

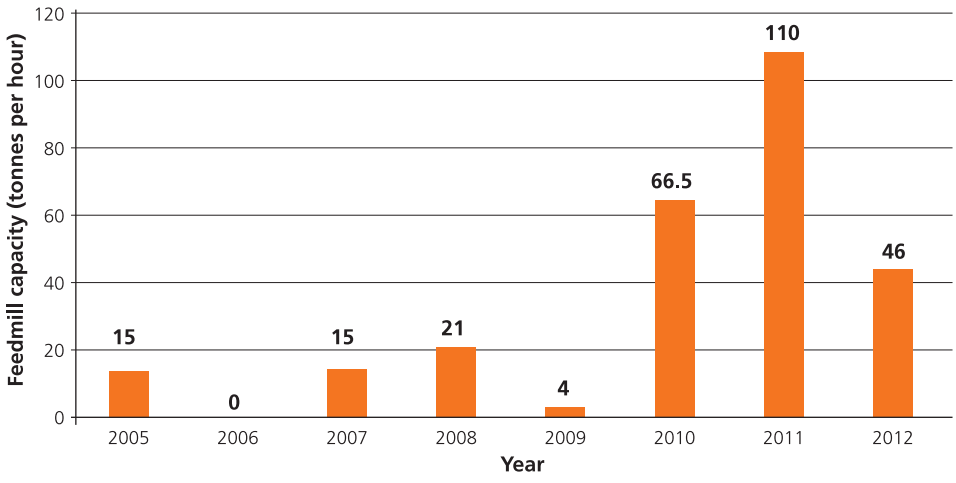
7.2 Impact of climate change on availability of carp feed ingredients

According to FAO estimates (Rana, Siriwardena and Hasan, 2009), India is projected to be one of the countries whose production of agricultural commodities is likely to be severely affected (28.8 percent reduction) due to climate change by 2080. Already several areas in the country that have produced abundant agricultural commodities are facing severe drought. Many areas that depend on groundwater to irrigate agricultural crops are facing water shortages, and bore wells in several areas have completely dried up. If the conventional feeding practices with high FCR (3.5:1) are employed, several challenges related to shortage of ingredients and water quality problems will have to be addressed. The adoption of pelleted feed-based carp culture production systems will help to increase profitability through the wise use of resources.

8. STATUS OF THE CARP FEED INDUSTRY IN INDIA

The commercial production of floating pellets for carps started in the year 2008 with a modest estimated production of 2 500 tonnes per month (30 000 tonnes per year), with soy meal incorporated at 35–56 percent. It has been estimated by the American Soybean Association – International Marketing (ASA-IM) that the sales of extruded soy-based floating fish feed will reach 500 000 tonnes annually by the year 2011 (Clark, 2009). Currently, India has an extrusion feed milling capacity of about 91 tonnes/hour and produces approximately 410 000 tonnes/year (estimate based on 75 percent mill efficiency, 20 hour operation per day and 25 working days a month). Rapid expansion in feed milling capacity is expected in 2011 and 2012 (Figure 14 and Table 7), when some major feed mills are expected to commence operation. It is predicted that this will boost annual fish feed manufacturing in India to about one million tonnes.

FIGURE 14
Development of extrusion feed mill capacity in India



Note: Estimated projection by the American Soybean Association – International Marketing/Soy in Aquaculture (ASA-IM/SIA); the figures represent the additional capacity installed/to be installed during each year.
Source: Vijay Anand, Cremer and Ramesh (2010).

TABLE 7
Development of extrusion feed mill capacity in India (tonnes/hour)

Company	2005	2006	2007	2008	2009	2010	2011	2012	Total
Indian Broiler	–	–	–	8	–	18+12	–	16	54.0
Uno	–	–	–	3 (X)	–	5+5+1.5	–	–	21.5
Kwality	1.5 (X)	–	1.5 (X)	–	4	4+1	10	–	19.0
Ananda	–	–	–	5	–	–	10	–	15.0
CP	–	–	–	5	–	–	20	–	25.0
Growel	–	–	–	–	–	10	10	–	20.0
Rudra	–	–	–	–	–	10	–	10	20.0
Nexus	–	–	–	–	–	–	15	–	15.0
Mulpuri	–	–	–	–	–	–	15	–	15.0
Cateroh	–	–	–	–	–	–	10	10	20.0
Indepesca	–	–	–	–	–	–	10	–	10.0
Sneha	–	–	–	–	–		10	–	10.0
Totals	**1.5**	**–**	**1.5**	**21**	**4**	**66.5**	**110**	**46**	**244.5**

Notes: This table presents in detail the new additional capacity installed and to be installed each year (if any) by various feed manufacturers. Figures marked 'X' are those feed mills which have given up small extruders and have expanded. Figures provided up to 2010 are on an actual basis; figures for 2011 and 2012 are forecasts and may change with varying plans of the investors, new investors and market developments.

Source: Vijay Anand, Cremer and Ramesh (2010).

In India, the manufacturing and marketing of floating pelleted feeds for finfish was initially taken up on a commercial scale in 2008 by three animal feed manufacturing enterprises, *viz*. the Indian Broiler Group, Uno Feeds and CP Feeds. Additionally, three more feed-manufacturing enterprises, *viz*. Ananda Feeds, Kwality Feeds and Growel Feeds also plan to enter into the production and marketing of floating soy-based fish feed on a commercial scale in India.

Feeding demonstrations have convinced the entrepreneurs of a good return on investment, and this has resulted in investments in fish feed manufacturing plants, despite a 35–40 percent duty on imported machinery. As many of these feed companies are focussing on striped catfish, it remains to be seen how much of these pelleted feeds will become available to the carp culture industry.

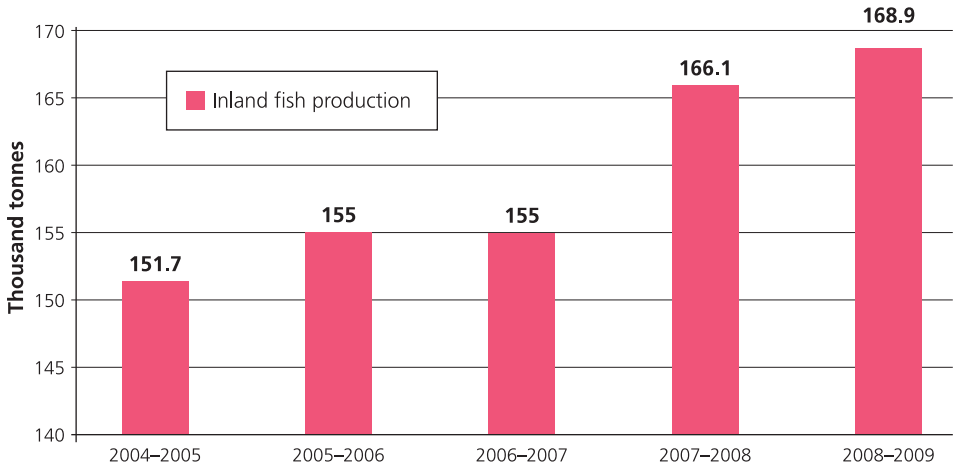
9. DEVELOPMENT OF A FEED-BASED CARP CULTURE SYSTEM IN TAMIL NADU

Tamil Nadu is one of the states that receive less rainfall, and thus people have evolved strategies to collect water during the monsoon by building reservoirs. The state has a long coastline and the marine capture fishery provides the major fish supply. The state has a number of river basins, with the Cauvery River basin being an important area for agricultural development. The reservoirs provide water for irrigation and other human necessities and have been contributing a substantial amount of fish to the capture fisheries sector (Figure 15). As the Cauvery basin has greater water availability than other regions, carp culture has been undertaken by farmers. As a result, carp production in Thanjavur district has improved substantially, largely because of the feeding practices adopted by farmers to increase fish growth rates and, consequently, overall production. The area being largely rice growing, rice bran is commonly available and is widely used as feed along with oil cake. In addition to these two principle ingredients, farmers also use maize powder, soybean flour and crude fishmeal[2] (made by grinding dry fish) in some places. These ingredients are mixed in various proportions, based on experience that is linked to natural food productivity in the ponds. In general, rice bran forms the major component (65 percent), and this is mixed with fishmeal at about 5 percent and the other ingredients (maize meal, soybean flour and oil cake) are added at about

[2] Generally referred to as fish powder.

10 percent each. Based on the natural food production and the growth of the fish, feeding is manipulated to minimize feed costs. Mash made of mixed feed ingredients is fed mainly by using feed bags. Although some farmers still broadcast the feed, a high percentage has adopted the bag feeding method.

FIGURE 15
Inland fish production (capture fisheries and aquaculture) of Tamil Nadu



Source: Anon. (2006); data for 2007 courtesy of Paul Pandian, Deputy Commissioner of Fisheries, Planning Commission, Government of India.

Table 8 shows that farmers in the Thanjavur District of Tamil Nadu have an average land area of 3.23 ha, with fish ponds covering an average of 2.17 ha. Most farmers have built ponds for fish culture, while some also reported the construction of ponds for water storage. Although direct integration of fish culture with other animals is not seen, most farmers have some animals on the farm, and the waste from these animals is used to increase pond productivity.

TABLE 8
Details of carp farming in the Thanjavur District of Tamil Nadu, India

Parameter	Conventional	Floating pellets	Mash + sinking pellets	Overall
Land area	2.8±2.3	3.42±3.1	3.53±4.2	3.23±3.6
Water area (ha)	1.84±2.0	2.75±2.5	1.9±1.3	2.17±2.0
Depth of pond (m)				
Maximum depth (m)	1.3±0.2	0.94±0.1	1.15±0.2	1.14±0.2
Minimum depth (m)	0.9±0.1	0.61±0.1	0.75±0.1	0.75±0.2
Age of the pond (year)	6.6±7.1	4.5±3.7	3.6±2.0	3.53±4.6
Purpose of construction				
Fish culture	13	8	6	27
Water storage	2	7	9	18
Integration[1]				
Rice	1		2	3
Cow	8	6	5	19
Pig	1	8		9
Poultry	8	7	3	18
Duck	4	5	2	11
Ownership of the pond		Single		
Type of operation		Polyculture		
Type of waterbody		Perennial (July–March)		

Notes: [1]Indirect, with the faeces (in the case of livestock, poultry and duck) of these components being used as fertilizers.
Source: Field survey (2010).

Although the use of pelleted feeds and commercially produced feed mixtures is gradually increasing, several farmers continue to prepare on-farm feed mixtures to reduce the cost of production. Some farmers join together to buy the necessary ingredients and grind and prepare the feed mix for use by farmers belonging to the group. This feed mixture is used in the early months of culture but once the fish attain a weight of 200–300 g the farmers switch over to pelleted feeds. The pelleted feeds, with their higher protein content and good stability, are used to promote the growth of carps. The yield of fish obtained by the farmers using floating pellets was consistently higher than that of the farmers using the other feeds (Table 9). Farmers using floating pellets can raise two crops per year through judicious stocking.

TABLE 9
Production details (kg/ha) observed for different feeding systems

Parameter	Conventional	Floating pellet	Mash + sinking pellet	Overall
Production (kg/ha/year)	3 010±643	4 596±501	4 432±2 579	4 012±1 687
Market price of fish (US$/kg)	1.38±0.13	1.56±0.09	1.43±0.15	1.46±0.14
Expenditures in harvesting (US$)	167.44±72.5	244.85±60.19	150.55±112.94	187.63±101.02
Size of harvested fish	>500 g			
Harvestings per year	Generally twice			

Source: Field survey (2010).

The use of floating pellets in carp culture has been promoted by organizations such as the American Soybean Association. As the feed companies demand cash payments, farmers with limited financial resources are not able to buy the feed. In shrimp farming, the supply of feed on a credit basis has become commonplace, but such a system has yet to be established in carp culture. Interestingly, yield, FCR and return on investment are better when floating pellets are used. Farmers using floating pellets for stock fish of a larger size (i.e. >50 g). These stunted large fish attain market size (400–600 g) in about six months and can then be harvested and sold. Depending on seed availability, and with proper planning, the farmers can raise almost two crops in a year.

Farmers using the conventional system resorted to significantly lower stocking densities, compared to the other two types of system. Interestingly, farmers used less inorganic fertilizers and less organic manure in both the floating and sinking pellet systems, and were thus able to maintain good water quality. These farmers also used less lime, compared to conventional-system farmers. Floating pellets are fed in net enclosures that prevent their dispersal and allow the fish to feed at one specified location. The amount of feed is also regulated based on the consumption pattern.

Farmers recognize the benefits of feeding with floating pellets, particularly with regard to economies in labour and ease of feeding, as summarized in Table 10. Furthermore, ponds fed with floating pellets have better water quality. While farmers appreciate these benefits, a lack of assured supplies of floating pellets is the major constraint at present. Floating feed plants that are located in Andhra Pradesh focus on the striped catfish farmers in that state, and only when there is a bulk order do they supply feed to the carp farmers of Tamil Nadu. In addition, the cost of transport contributes to the increased cost of feed.

TABLE 10
Type of formulated feed used for carp culture with advantages and disadvantages and the type of processing

Type	Advantages	Disadvantages	Moisture (% max)	Processing techniques
Farm-made				
Dry	Use of locally available ingredients; easy to prepare using simple household machines; as moisture content is less, more durable than moist feed and cheaper	Poor water stability; poor digestibility; poor FCR; and rapid water quality deterioration	10	Grinding, mixing and drying
Moist	Easy processing; cheaper.	Highly perishable	>30	Wet dough
Commercially manufactured pellets				
Sinking	Good water stability and digestibility; good for bottom feeders	Not suitable for fish occupying surface and midwater levels	10	Pelleted
Floating	Good for surface feeders and larval fish	Not useful for bottom feeders	10	Extruded

The price of the various commercial feeds in the area is presented in Table 11. Feeds are supplied by the producers on a cash and carry basis. Since the transportation of small quantities is not considered economically viable by these companies, the dealers are not able to provide the supply when the collective order of the farmers is less than 10 tonnes per batch. This is a major hurdle to the rapid spread of floating feed usage. Although floating pellets are expensive, compared to sinking pellets and mash feeds, the farmers are happy with the results of their use. Hence, if there were an assured supply, farmers would be likely to switch to using floating pellets on a large scale.

TABLE 11
Price of various feeds used by the carp farmers

Manufacturer's price of feed (US$/kg)				
Type of feed	**Gold Mohur**	**CP**	**Uno**	**Farm-made**
Mash	–	–	–	0.27
Sinking pellet	0.33	0.39	–	–
Floating pellet	0.5	–	0.44	–
Market price per kg of raw ingredients used by farmers (US$)				
	De-oiled rice bran	Soy flour	Maize flour	Crude fishmeal
Price	0.24	0.55	0.28	0.65

Source: Field survey (2010).

The nutrient composition of the different types of feed used indicates that the protein level of all three types is almost the same but floating pellets have a higher percentage of fat and a lower fibre content (Table 12). However, the processing method has a major influence on nutrient availability and, as a result, floating pellets have been inducing good growth when compared to other feed types.

TABLE 12
Various feeds and their proximate composition (% dry matter)

Size (mm)	Crude protein (min)	Crude lipid (min)	Crude fibre (max)	Moisture (max)	Net weight per bag (kg)
Mash feed					
0.89	32	3.5	8	12	20
1.41	32	3.5	8	12	20
Sinking pellet					
2.3 x 3–5	31	3.5	8	12	20
2.3 x 6–12	30	3.5	8	12	20
Floating pellet					
1.5	32	6	4	10	20
3	32	6	4	10	20
4.5	31	6	4	10	20
6	30	6	4	10	20

Source: Field survey (2010).

10. ECONOMICS OF CARP CULTURE IN TAMIL NADU WITH DIFFERENT FEED-BASED SYSTEMS

As in all other areas of the country, carp farming in Tamil Nadu has proved to be more profitable then paddy cultivation. As a result, the aquaculture industry is growing rapidly in the state and this is contributing to the increased availability of fish to local populations. Most of the fish produced is sold locally, and farmers are able to get a good farm-gate price. Although the existing demand for fresh fish far exceeds local production, due to inefficient marketing mechanisms farmers are not able to obtain the best price for their produce on a sustained basis. In the present study (Table 13), the best benefit-cost ratio was observed when farmers used floating pellets (1.6), while those using the conventional feed mixture (1.4) and sinking pellets (1.5) obtained lower levels of return. The higher cost of sinking pellets, coupled with the low production level, contributed to reduced economic returns. The total and net returns were higher for floating pellets, compared to other types of feeding practices, but were lowest for the conventional system. Similarly, the benefit-cost ratio remained higher for floating pellets (Table 13 and Figures 16–19). It is evident from the study that by adopting quality feed, return on investment can be improved. These benefits are well recognized by the farmers and their concern relates to the need to make floating pelleted feeds available without interruption. If the supply chain could be well established, it is likely that the farmers would accept the new technology.

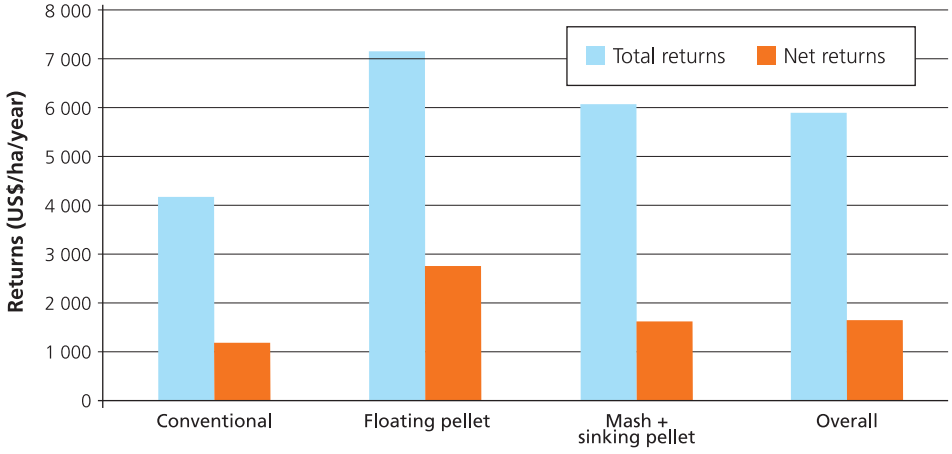
There are various opportunities by which the profitability of the system can be further improved by adopting improved management strategies. The use of larger seed and stunted seed would be beneficial, particularly in the case of Indian major carps (e.g. rohu and mrigal). Furthermore, by improving marketing support, there is good opportunity to increase profitability.

TABLE 13
Economics of production observed in different diet-fed systems (US$/ha/year)

Parameter	Conventional	Floating pellet	Mash + sinking pellet	Overall
Variable costs				
Seed	97.0	826.9	148.7	234.2
Fertilizers	40.6	16.6	20.6	18.9
Manure	113.3	85.6	65.9	88.3
Feed	1 643.0	2 541.9	3 294.5	2 864.6
Lime	138.0	11.8	43.9	100.7
Labour	118.3	114.7	121.2	127.1
Pumping	196.4	188.1	183.2	197.7
Harvesting expenses	167.4	244.9	150.6	187.6
Subtotal	2 513.9	4 030.3	4 028.4	3 819.1
Fixed costs				
Lease amount	271.6	200.6	256.2	242.8
Depreciation	27.8	27.8	27.8	27.8
Interest	166.7	138.9	148.2	151.9
Subtotal	466.1	367.3	432.1	422.4
Total cost	**2 968.9**	**4 397.6**	**4 460.5**	**4 241.5**
Total returns	4 141.1	7 148.2	6 073.5	5 869.4
Net returns	1 172.2	2 750.6	1 613.0	1 627.9
Benefit-cost ratio on TVC1	0.03	0.03	0.02	0.03
Benefit-cost ratio on TC1	0.03	0.03	0.03	0.03
Break-even price	0.98	0.94	1.00	1.06
Actual price	1.37	1.56	1.43	1.46

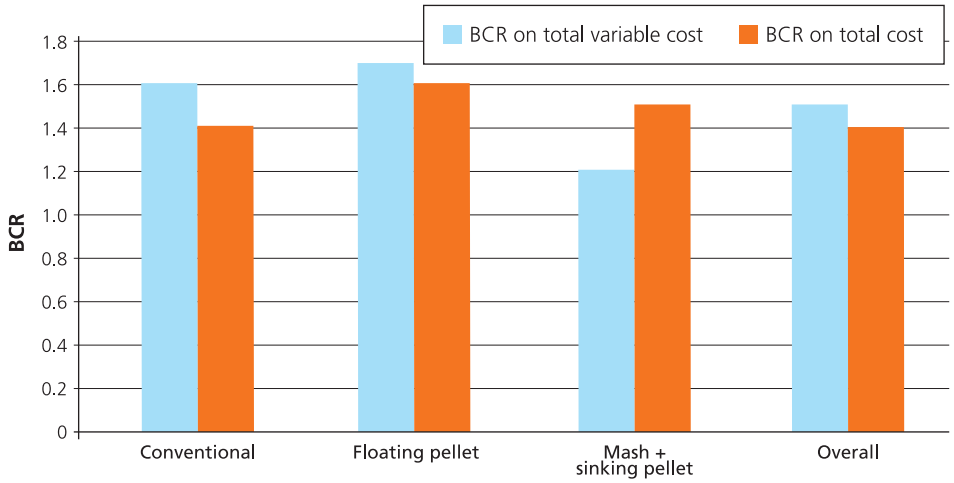
Notes: [1]TVC = total variable cost; TC = total cost.
Source: Field survey (2010).

FIGURE 16
Total and net returns (US$/ha/year) of different diet-fed carp culture systems



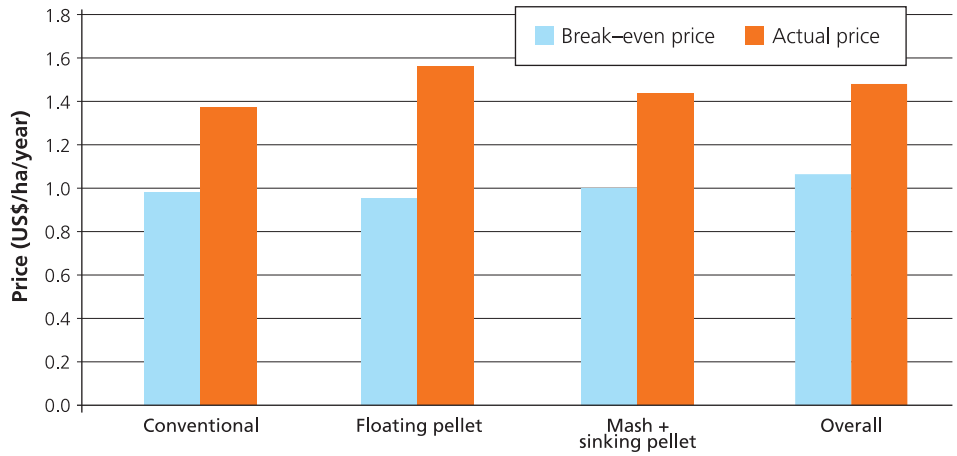
Source: Field survey (2010).

FIGURE 17
Benefit-cost ratio (BCR) of different diet-fed carp culture systems



Source: Field survey (2010).

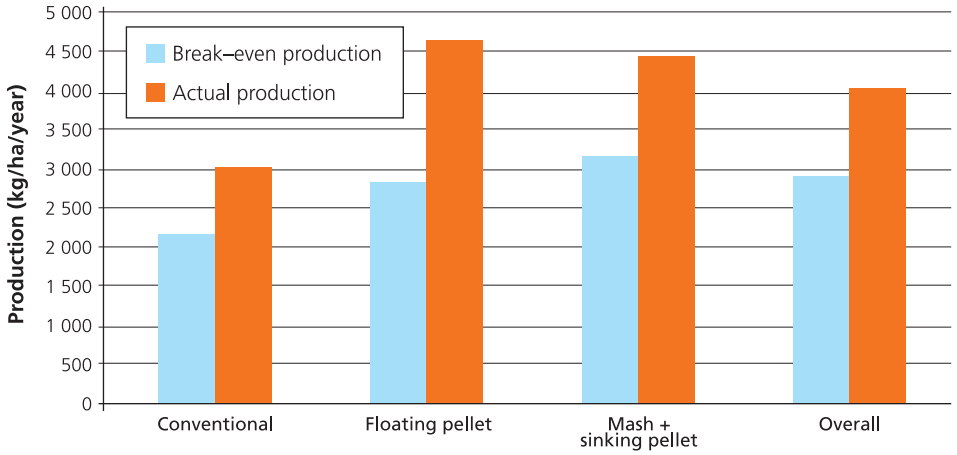
FIGURE 18
Break-even and actual price (US$/ha/year) in various diet-fed carp culture systems



Source: Field survey (2010).

In general, from paddy cultivation farmers are able to obtain a profit of US$ 363–556/ha/year. In contrast, aquaculture farmers have been able to obtain almost double this amount. Hence, planned intervention to convert unproductive and unused paddy cultivation areas to fish culture would help in generating additional income and improving food quality.

FIGURE 19
Break-even and actual production (kg/ha/year) in diet-fed carp culture systems

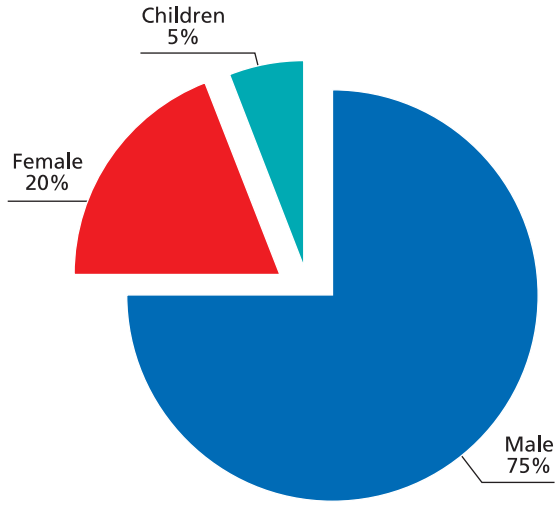


Source: Field survey (2010).

11. GENDER ROLE IN AQUACULTURE PRODUCTION OF TAMIL NADU

In Tamil Nadu, the participation of women in aquaculture is very limited, both in culture-related activities and in the marketing of freshwater fish. However, in some families women are involved in feeding and other aquaculture management activities (Table 14 and Figure 20). As the rural society in India still follows a patrilineal system, planned intervention strategies are needed to increase the role of women in aquaculture and gradually to build their knowledge. When queried about the poor participation of women in aquaculture, most men felt that it was not the tradition, while most women felt that the involvement of their husband was enough to manage the activity. As many aquaculture activities (e.g. feeding, fertilization, pond care) are better managed by women, their involvement would help to increase production, while men could attend to other farm activities.

FIGURE 20
Participation of family members in aquaculture activities



Source: Field survey (2010).

TABLE 14
Involvement of family members in aquaculture activities

Family members	Average overall activity (%)	Activities
Males	75	Water exchange, pond maintenance, etc.
Females	20	Feeding and marketing
Children	5	Feeding

Source: Field survey (2010).

12. PROBLEMS ENCOUNTERED BY FARMERS

Carp farmers face various hurdles in their farming practices. The major problem relates to the non-availability of pond inputs, particularly pelleted feeds. Although the farmers realize the benefits of using compounded pellets for carps, they are confronted with high prices and their lack of availability in many areas. The carp feed and animal feed mills that engaged in the manufacture of pelleted feed for carps on a commercial scale are located only in certain regions of the country. As a result, farmers of those particular regions and, to a certain extent of neighbouring regions, enjoy good availability of adequate quantities. However, a major constraint is that the feed manufacturing enterprises have not yet established efficient marketing networks and strategies so that their products are available at a reasonable cost to farmers distant to their production sites.

The feeds produced locally by farmers through small feed units do not have a long shelf life and hence cannot be prepared in bulk and stored. This problem could be addressed by the initiation of social bodies such as farmer cooperatives. By doing this, the small farmers would be able to obtain the required quantities of feed at a reasonable price, which would provide net benefits and the eventual intensification of carp farming.

The marketing of farmed fish and the ability of obtaining a good farm-gate price for them is another challenge faced by the farmers. This can be achieved by adopting pellet-fed farming and better management practices (BMP), thus ensuring that the harvested fish are of high quality and fetch a good market price. Live fish marketing is becoming popular, especially in the northern regions of the country and also in some southern parts of India. In addition the Indian Government is taking measures through the central sector scheme to strengthen the infrastructure for inland fish marketing; specifically to improve marketing channels through the establishment of fish marketing outlets/kiosks.

The availability of credit at the right time and at low interest rates is another constraint that has particularly affected small farmers. This is now being addressed by the agricultural credit policies of the Indian Government. A recent study conducted on the credit availability and utilization patterns of carp farmers in the Thanjavur district of Tamil Nadu (Ramkumar, 2010) revealed that the amount of credit provided per unit area by government financial institutions is more for small farmers than for large- and medium-scale farmers.

A lack of technical support from the institutions involved in aquaculture activities is recognized as an additional problem that could be solved by the provision of effective extension services by the research institutes, Krishi Vigyan Kendra (KVK; farm science center) and non-governmental organizations (NGO) involved in fisheries and aquaculture.

Electricity supply was identified as a common problem by almost all the farmers. Currently, electricity used for aquaculture activities is charged at industrial rates, which is burdensome to the farmers. As agricultural activities have been provided with free electricity, fish farmers have naturally been demanding that electricity should be provided for them at reduced or subsidized tariffs.

13. CONCLUSIONS

Although India is the second largest aquaculture producer globally, the gap between the production levels achieved by research and that accomplished by farmers is still very high. Although a high percentage of resource-rich farmers in Punjab and Andhra Pradesh have been able to bridge this gap through their own innovations and the efficient use of feed resources, many farmers continue to obtain yields of less than 2 500 kg/ha/year. Bridging this gap between actual and potential production through the creation of additional support services, such as access to feed supply systems,

increased availability of credit, improved availability of quality seed, etc. will help to augment production.

Furthermore, the additional aquatic resources and new areas that are becoming available (e.g. saline-affected soils) will help to increase aquatic production, if efficient marketing systems are provided that enable farmers to obtain the best price for their produce. The development of local marketing systems will help both consumers and producers in the long run. Although a high demand for carp still exists in the eastern part of the country, value addition through processing and the creation of products directed at non-traditional consumers is recognized as key to the success of carp culture development in India.

Aquaculture is dependent on agricultural and fishery resources for fertilizers and feed inputs. Effective utilization of the feed ingredients is an essential requirement for sustained development of the aquaculture sector in India. There will be increased competition for these agricultural by-products from the livestock and poultry sectors, and hence continued research to keep production costs low and market prices affordable to consumers is essential. Increased competition between users may lead to a rise in the cost of feed ingredients and farm inputs; hence there is a need to identify new resources that can be cost effective in aquaculture.

Climate change is expected to threaten the sustained production of agricultural commodities that are the sources of the major inputs to aquaculture. Hence, there is a need for the judicious allocation and use of available feed resources by adopting efficient feed management practices such as:

- using high conversion-efficient diets (thereby minimizing the amount of feed used per unit of fish produced);
- minimizing feed wastage;
- using alternate/mixed feeding schedules; and
- improving feed ingredient processing for better digestibility and conversion efficiency.

These improvements can only be achieved by switching from conventional feed mixtures to compounded feed pellets. The Indian carp culture industry has not moved to pelleted feeds because of the non-availability of feeds that can be used economically. This situation is changing rapidly with the establishment of a large number of feed factories, with demonstrations being given to prove the economic viability of the fed aquaculture systems.

The coming decade is expected to bring all these positive changes and an increase in carp production. With the approval of striped catfish and tilapia as aquaculture species, the aquaculture situation in India may change; however, carps will continue to dominate for at least another decade.

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A review of on-farm feed management practices for North African catfish (*Clarias gariepinus*) in sub-Saharan Africa

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ABSTRACT

This review considers feed management practices for North African catfish (*Clarias gariepinus*) in sub-Saharan Africa. Clariid catfish production in the subcontinent is increasing exponentially, particularly in Uganda. Semi-intensive pond culture is still the most prevalent production system, while intensive tank culture is becoming more popular in peri-urban areas in Nigeria. Total production in these two countries now exceeds 178 000 tonnes annually. Catfish are now commonly spawned and their larvae reared in hatcheries for ten to 14 days, after which they are reared in nursery ponds or in tanks. Extensive rearing of larvae, after yolk sac absorption, in ponds is now less often practiced than in the past. Where it is still practiced, successful larval rearing and satisfactory survival rates depend mainly on adequate fertilization schedules. Feed management practices in hatcheries are closely matched with the physiological and endocrinological ontogeny of the fish. For optimal survival and growth, live food (mainly Artemia) is required for the first five days after the start of exogenous feeding, after which the fish can be weaned onto a dry starter feed. Up to a size of 5 g, the species has a high protein demand (>50 percent). Extensive farming of catfish in ponds is largely a subsistence activity and is practiced mainly in polyculture with tilapia that serve as fodder fish, and using a single ingredient feed such as maize or wheat bran. Semi-intensive on-growing of catfish in static and flow-through ponds, as well as under high-density tank culture conditions requires a complete feed; production levels achieved in these three systems are 15–24 tonnes/ha/cycle, 40 tonnes/ha/cycle and 385 kg/m^3/cycle, respectively. Results show that floating extruded pellets with a protein content of 30–35 percent are preferred by farmers. The duration of the grow-out cycle depends on the size of fish required by the market. At temperatures between 26 and 28 °C the fish can be grown from 1 g to 800 g in seven months. Feed conversion ratios (FCR) are

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size dependent, and best ratios are obtained by feeding the fish to satiation while observing their feeding response. Daily ration tables serve largely as a guideline. In ponds, the fish are fed two to three times per day, while under high-density tank conditions they are fed five to six times per day. During the early juvenile phases (1–24 g), FCR are commonly <1:1; from 25 g to 800 g FCR of 1.2:1 are achievable. There have been significant advances in feed availability and quality in the region, particularly in Uganda, although it would appear that weaning diets and starter crumbles are still being imported.

1. INTRODUCTION

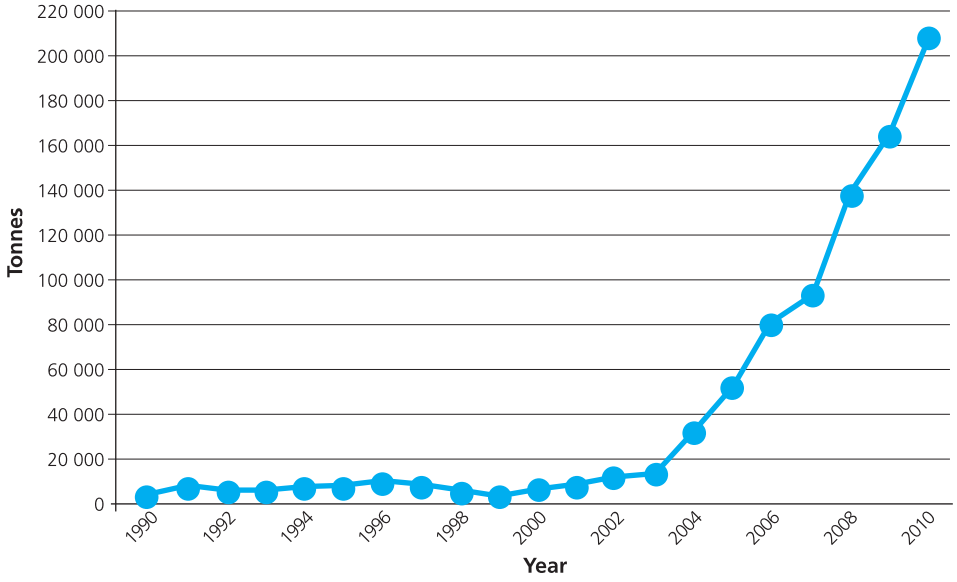
While the aquaculture attributes of the North African or sharptooth catfish, *Clarias gariepinus* have been recognized since the 1940s (Hey, 1941), the basic technologies and protocols for the farming of the species were developed much later, mainly from the 1960s to the late 1990s (e.g. Micha, 1971, 1972; El Bolock, 1973; De Kimpe and Micha, 1974; Richter, 1976; Hogendoorn, 1979, 1981; Bok and Jongbloed, 1984; Viveen *et al.*, 1985; Verreth and Den Bieman, 1987; Hecht, Uys and Britz, 1988; De Graaf and Janssen, 1996,). These studies provided the basic information upon which the future research and farming of North African catfish would be founded. Many mistakes were made along the road to commercialization (Hecht, Oellermann and Verheust, 1996), and it is only in the more recent past (i.e. in the first decade of the new millennium) that *C. gariepinus* farm production figures for sub-Saharan Africa (Table 1) have become significant (Figure 1), particularly in Nigeria and latterly in Uganda (Figure 2). The growth of the catfish farming industry in Nigeria was market driven, while the spike in production in Uganda in 2006 is generally regarded as a combination of market forces and a well-directed donor project initiative (Isyagi *et al.*, 2009a). According to FAO (2012), North African catfish was the most important commercial aquaculture species in 2010 in sub-Saharan Africa (198 296 tonnes), followed by Nile tilapia (*Oreochromis niloticus*) (60 350 tonnes). The farming of *C. gariepinus* in Europe is a minor activity (FAO, 2012) and is currently occurring only in the Netherlands, Hungary and Poland (1 810, 3 200 and 650 tonnes, respectively, in 2010). In Asia, *C. gariepinus* is hybridized with *C. batrachus* and *C. macrocephalus*. Clariids are an important component of the total farmed fish production in the Asia Region, which in 2010 contributed a production of 453 209 tonnes (FAO, 2012).

TABLE 1
Total production (tonnes) of clariid catfish in Africa, 2004 to 2010

	2004	2005	2006	2007	2008	2009	2010
Egypt	459	10 180	6 058	5 287	13 944	17 895	9 717
Kenya	320	318	302	890	935	1 047	2 188
Nigeria	26 750	34 582	51 916	52 229	86 130	89 193	130 318
Uganda	3 827	6 528	20 941	34 096	35 000	54 956	63 000
Other (n=22)	721	617	922	1 037	1 159	1 669	2 790
Sub-Saharan subtotal	31 618	42 045	74 081	88 252	123 224	146 865	198 296
Total	**32 077**	**52 225**	**80 139**	**93 539**	**137 168**	**164 760**	**208 013**

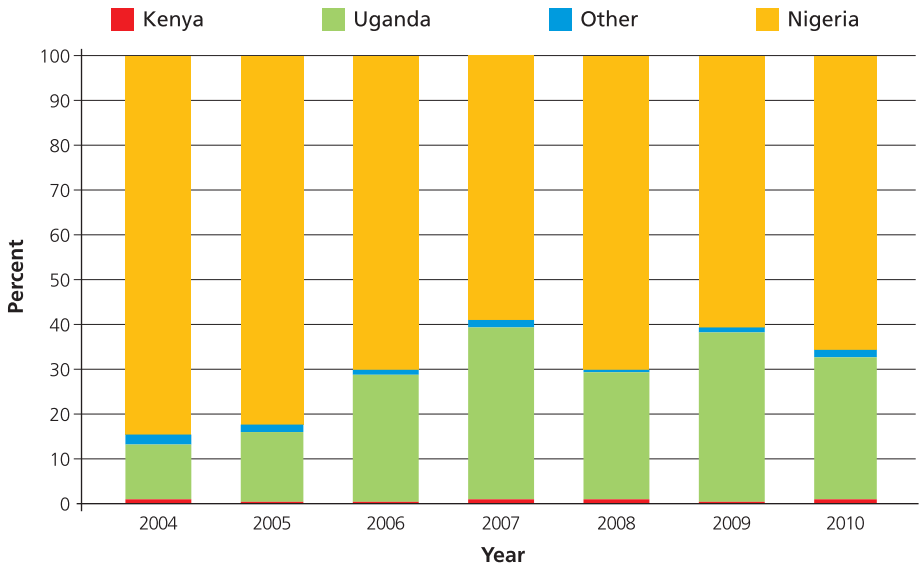
Source: FAO (2012).

FIGURE 1
Clariid catfish production in Africa, 1990 to 2010



Source: FAO (2012).

FIGURE 2
Percent contribution by major[1] sub-Saharan clariid catfish producer countries[2]



[1] Defined as having a production of >1 500 tonnes in 2010.
[2] The 'other' category consists of 22 sub-Saharan countries in which clariid catfish are also produced in lesser quantities.

Source: FAO (2012).

The significant increases in annual production in sub-Saharan Africa from around 2000 onwards can be partially ascribed to the concerted research efforts on the nutritional requirements of the species during all life history stages, feed formulation, optimization of feeding and feed management practices and the development of high-density tank farming practices. However, more importantly, there has been a switch in the profile of catfish farmers from small-scale rural farmers to educated, mainly urban-based, young entrepreneurs who have easier access to capital and for whom access to information is less difficult. In sub-Saharan Africa, clariid catfish are farmed in one of three basic ways *viz*. extensive polyculture in ponds, semi-intensive pond culture and intensive tank culture.

In smallholder ponds, the fish either contribute to some extent towards improved nutrition at the household level or (when produced in surplus), are (rarely) sold for cash. The fish are normally produced in polyculture with tilapiine species that serve as fodder fish. The most common feed used under this scenario is maize or wheat bran (from which the catfish also benefit marginally), and some (normally inadequate) quantity of manure, compost and possibly some fertilizer are applied. Under this scenario, production rarely exceeds 1.5 tonnes/ha/year, which equates to ~30 kg of fish per 200 m^2 pond per annum.

Commercial-scale production of catfish in ponds takes place in various ways. Under monoculture, static pond or flow-through conditions, the fish are normally fed on a complete, pelleted feed or on farm-made feeds. Production levels under static pond conditions range from 15–20 tonnes/ha/cycle. Under flow-through conditions, production ranges between 25 and 40 tonnes/ha/cycle. In polyculture conditions in stagnant ponds, catfish are often grown together with *O. niloticus* and fed on farm-made feeds, with total yields ranging from 5 to 8 tonnes/ha/year (Ayinla, 2007). During the period 1985 to 1998, there was a concerted research effort on high-density tank farming of *Clarias gariepinus* under recirculating conditions (Oellermann and Hecht, 1996; Eding and Kamstra, 2002; Eding *et al.*, 2006). This technology was first put into practice in the Netherlands and is now commonly used in Nigeria, Hungary and Poland. It should, however, be noted that the bulk of catfish in Nigeria and Uganda is still produced in ponds (Akinwole and Faturoti, 2007; J. Rutaisire, Department of Fisheries, Uganda, personal communication 2010). High-density tank farms in Nigeria, and now also in Uganda, are situated mainly in peri-urban environments and in other areas where there is ready access to supplies and services (Akinwole and Faturoti, 2007).

In Uganda and Kenya, *C. gariepinus* is not only farmed commercially as a food fish, but fingerlings are also produced as live baitfish for the Nile perch (*Lates niloticus*) fishery in Lake Victoria. Currently the demand for 8–10 g fingerlings as live bait is around 700 million per year in the Lake Victoria basin area, while the demand in Uganda alone is around 300 million per year (Isyagi *et al.*, 2009a, b).

This paper reviews current and best on-farm feeding and feed management practices during the various life history stages. Based on current practices, several recommendations are provided within the text that may help to improve production and feed conversion ratios (FCR) and lead to reduced levels of waste.

2. FEEDING OF LARVAE AND EARLY JUVENILES

Catfish larvae are generally reared to fingerlings in one of three ways;

- Under commercial farming conditions, they are either intensively reared to fingerling size solely in a hatchery, after which they are on-grown under pond or high-density tank culture conditions.
- Alternatively, they are reared in a hatchery for a period of up to 14 days and then grown to fingerling size for a further 30 + days in nursery ponds, after which they are stocked into larger on-growing ponds.
- Extensive larval rearing encompasses the stocking of 3-day-old larvae into well prepared and protected nursery ponds, where they are on-grown to fingerling size before being stocked into larger grow-out ponds.

The feed to be used and the applied feeding strategy are largely dependent on whether the larvae are reared extensively or intensively.

2.1 Extensive rearing

Under extensive rearing conditions, the ponds are prepared such that there is an abundance of zooplankton. This takes place up to 14 days prior to stocking and consists of liming and fertilization. ASEAN (1978) and Viveen *et al.* (1985) recommend the use of 100–150 kg/ha of quicklime, which is added to the damp pond bottom to eliminate pathogens and invertebrate predators. The pond is then left for 7–14 days, after which it is filled with water to a depth of 30 cm and the pH of the water adjusted by adding agricultural lime. Ensuring a good zooplankton bloom requires adequate fertilization with chemical or organic fertilizers. The choice of either is largely determined by availability and the economic circumstances of the farmer. The main inorganic fertilizers used are super-phosphate (approximately 20 percent P_2O_5), triple super-phosphate (45 percent P_2O_5), urea (about 45 percent N) and NPK 15:15:15 (15 percent N, 15 percent P_2O_5 and 15 percent K_2O). It is strongly recommended to dissolve the fertilizers and then to spread the solution evenly over the water surface (ASEAN, 1978). In the absence of any specific work on North African catfish fry or fingerling rearing ponds, it is advisable to follow the findings and recommendation made by Hepher (1963, 1967) and Boyd (1982). The work by Hepher (1963, 1967) has shown that applying fertilizer doses greater than 0.5 mg P/L or 1.4 mg N/L has no biological or economic justification. These levels are equivalent to application rates of 60 kg/ha of single super-phosphate (11 kg P_2O_5/ha) and 60 kg/ha ammonium sulphate (13 kg N/ha) respectively, applied at two-weekly intervals (0.8–1.0 m water depth, 8 000–10 000 m^3 water/ha) (Tacon, 1987, 1988). Similarly, Boyd (1982) recommends chemical fertilization strategies to maintain soluble nitrogen and orthophosphate at 0.95 mg N/L and 0.1–0.5 mg P/L, respectively.

The most commonly used organic fertilizers are chicken, pig and cow manure. Table 2 shows several application schedules. It is important to note that the application rates are not absolute and only serve as guidelines. If an adequate phytoplankton bloom is not achieved within six to eight sunny days, then more manure should be added. Plankton levels are adequate when the water has a green colour and a Secchi disk reading of around 20–25 cm. The biological effect of organic fertilization is improved if the manure is spread evenly over the water surface in a liquid or semi-liquid form (Tacon, 1988). Fish ponds can only assimilate a certain amount of manure per day. Hence to prevent de-oxygenation in manure-loaded ponds (due to unchecked peaks in bacterial growth and phytoplankton blooms), manure should be added frequently (daily, if possible) and in small amounts, and during mid-morning when oxygen levels are rising (Hepher and Pruginin, 1981).

Table 3 shows a mixed (inorganic and organic) fertilization schedule that can also be used to develop good zooplankton blooms.

TABLE 2
Fertilization rates using animal manure

Fertilizer	Rates (kg dry weight/100 m^2)
Poultry manure	25 kg initially and then 3–5 kg every 10 days
Pig manure	7 kg every 2nd day
Cow dung	10 kg every 2nd day

Source: Tacon (1988).

TABLE 3
Combined fertilization rates

Manure/fertilizer	Rate (kg/week/100 m²)
Dry poultry manure	10–20
Urea	0.4–0.8
Triple superphosphate	0.1–0.2

Source: Janssen (1985).

Periphyton can also be used successfully for the rearing of *Clarias* larvae (Nwachukwa, 1999). Amisah, Adjei-Boateng and Afianu (2008) have demonstrated the beneficial combined effect of pond fertilization and the use of bamboo poles for the development of periphyton. In their study, bamboo pole density was 4 per m² and ponds were fertilized with pig manure at an initial rate of 20 kg/100 m² and then every second week at 10 kg/100 m².

Clarias larvae start exogenous feeding approximately 80 hours after hatching (depending on temperature) and are therefore normally transferred into well prepared and protected nursery ponds when they are three days old. Nursery ponds vary in size between 100 and 250 m²; in sub-Saharan Africa nursery ponds must be protected against the African clawed toad, *Xenopus laevis*, by way of a smooth wall made of plastic, roof sheeting or other suitable material. If this precaution is not taken, then the majority, if not all, of the fry will be lost to predation. The ponds are stocked at a density of 100–250 larvae/m². From the day of stocking, the fish must receive supplementary feed. At a density of 100 fry/m² the recommended feeding levels are 1 kg rice or wheat bran, plus 1 kg/100 m² of crumbled, formulated feed containing some fishmeal for the first three weeks. For the following two weeks, the bran ration remains the same but the formulated feed ration increases to 2 kg/100 m²/day, fed in two equal meals. After three weeks, it is advisable to grade the fish into two or three size groups to reduce cannibalism. With good feeding and management practices, survival rates of 40 percent and a final fish weight of 3 g can be achieved during 50-day rearing cycles (De Graaf and Janssen, 1996). These authors are also of the opinion that the most critical factor (on condition that the pond is protected) is most probably the availability of zooplankton during the first few days of the rearing cycle.

2.2 Intensive rearing

The larval rearing protocol under intensive hatchery rearing conditions is completely different and is very closely allied to the ontogeny of the alimentary and endocrine systems. It normally lasts for a period of 12 to 14 days and ideally takes place at the optimum temperature for growth (28 °C).

Research has shown that live food in the form of enriched *Artemia* nauplii, small *Daphnia*, *Moina* or other zooplankton of suitable size is essential for the first four to six days after the start of exogenous feeding (Hogendoorn, 1980; Uys and Hecht, 1985; Verreth and van Tongeren, 1989; Haylor, 1993; Hecht, 1996; Awaiss and Kestemont, 1998) and is preferable to dry food only (Appelbaum and van Damme, 1988). The reason for this is that the stomach of the larvae is not functional at the start of exogenous feeding (three days after hatching), and its development extends beyond the eleuthero-embryo stage into the larval stage (Stroband and Kroon, 1981). The stomach only becomes functional four to five days after the start of exogenous feeding (Verreth *et al.*, 1992; Segner *et al.*, 1993). Once the stomach becomes functional and pepsin activity contributes significantly to protein digestion, the larvae can be weaned from live food to a dry feed (Verreth and van Tongeren, 1989; Verreth *et al.*, 1993).

Larvae and early juveniles of *C. gariepinus* (up to approximately 5 g) have a high protein demand of around 50–55 percent and a lipid requirement of 9 percent (Uys and Hecht, 1985), of which at least 10 percent should consist of fish oil (Uys, 1989; Kerdchuen, 1992). The carbohydrate content can be as high as 21 percent of the diet (Uys and Hecht, 1985). For optimal growth, the composition of any dry feed that will be fed from 5 or 6 days after hatching (dah) until at least 14 dah must meet the nutrient requirements as outlined above.

Several larval and early juvenile rearing protocols have been developed. The four most commonly used protocols are shown in Table 4; all result in good growth and survival rates. Optimum pellet crumble size during this period is 2.2 percent of the mean total length of the larvae, and early juveniles should be fed at 25 percent of body weight per day at two-hour intervals (Uys, 1984). Predicted feeding rates are also provided by Verreth and Den Bieman (1987). Production costs can be significantly reduced by using small-strain *Daphnia* instead of *Artemia*.

TABLE 4

Four feeding protocols for North African catfish, *Clarias gariepinus*[1]

Protocol 1 (dah)[2,3]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**15/16–30/32**
Artemia			→	→	→	→	→	→								
Weaning diet			→	→	→	→	→	→	→	→	→	→	→	→	→	
Grow-out feed															→	→
Protocol 2 (dah)[4]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**15/16–30/32**
Artemia			→	→	→	→	→	→	→							
Weaning diet												→	→	→	→	
Grow-out feed															→	→
Protocol 3 (dah)[5]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**15/16–30/32**
Artemia			→	→	→	→	→	→	→							
Weaning diet								→	→	→	→	→				
Grow-out feed												→	→	→	→	→
Protocol 4 (dah)[6]	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**15/16–30/32**
Artemia			→	→	→	→	→	→	→	→	→	→	→	→		
Weaning diet/bran															→	→

[1] Larvae start exogenous feeding ca. 80 hours after hatching

[2] Protocol 1 (Hecht, Uys and Britz, 1988): *Artemia* is presented to the fish once a day

[3] dah = days after hatching

[4] Protocol 2 (Verreth, Storch and Segner, 1987): *Artemia* restricted up to four times per day

[5] Protocol 3 (Oellerman, 1995): *Artemia* restricted up to four times per day

[6] Protocol 4 (Janssen, 1985; De Graaf and Janssen, 1996): *Artemia* presented ad libitum

After 12–14 days, the fry are stocked into nursery ponds at densities ranging from 65 to 2 000/m^2 (Viveen *et al.*, 1985; Hecht, Uys and Britz, 1988; Isyagi *et al.*, 2009b). The density at which fry are stocked depends on fish age and the intensity of rearing protocols. Under pond-farming conditions, it is recommended to feed the fry three times per day at 25 percent of body weight per day, using a 38–40 percent protein diet (Hecht, Uys and Britz, 1988). If the larvae and early juveniles are reared in tanks, then the feed should have a protein content of around 50 percent. When the fish attain an average weight of 1–2 g, they are ready to be stocked into ponds or tanks for on-growing.

Cannibalism is a serious problem during larval and early juvenile rearing, particularly under hatchery conditions (Hecht and Appelbaum, 1988). The rate of cannibalism is affected *inter alia* by feeding frequency, food availability, light intensity and photoperiod (Hecht and Pienaar, 1993). Almazán, Schrama and Verreth (2004) showed that a reduction in swimming activity results in a lower incidence of aggressive behaviour. Hence feeding frequency, food availability and light intensity must be manipulated such that swimming activity is reduced to a minimum. This is achieved at low light intensity (<15 lux), continuous food availability and feeding the fish every two hours around the clock.

3. FEEDING DURING ON-GROWING

The species is produced in widely different farming systems ranging from highly intensive tank culture under flow-through or recirculating conditions to intensive, semi-intensive and extensive (small and large-scale, polyculture or monoculture) static or flow-through pond-culture systems. It is therefore not surprising that a wide range of feeds are used in the farming of this species. These include dry feeds ranging from single ingredient dry feeds, such as maize bran, to farm-made mixed feeds to formulated, floating or slow-sinking, extruded pellets, as well as single ingredient or mixed moist, farm-made feeds (Hecht, 2013).

The optimum pond size for catfish production was found to be 0.1 ha. This allows for optimum control of feed use and management of the production and harvesting cycle (Hecht, Uys and Britz, 1988). Under pond-farming conditions using formulated feeds, it is best to train the fish to feed in the same area of the pond at the same time of day. This is easily achieved and has several advantages. It allows the farmer to take good samples with which to assess average fish weight and fish health and ultimately facilitates harvesting. It is further recommended to feed the fish based on their feeding response. This allows the fish to be fed to satiation on a daily basis under variable environmental conditions (e.g. temperature, dissolved oxygen, pH, nitrogenous metabolites, barometric pressure), all of which affect daily feed intake. Feeding charts should serve as a guide to estimate daily rations (Table 5). During the on-growing cycle in ponds, fish are normally fed twice a day. It is an essential management practice to maintain good records of the daily amounts fed and the feeding response of the fish (Hecht, Uys and Britz, 1988; Isyagi *et al.*, 2009b).

TABLE 5

Recommended daily ration for North African catfish (expressed as % body weight/day)

Temperature (°C)	Fish size (g)					
	1–10	10–25	25–50	50–100	100–300	300–800
16	1.0	0.6	0.4	0.3	0.2	0.2
18	3.0	1.6	1.0	0.8	0.6	0.5
20	5.0	3.0	2.0	1.5	1.2	1.0
22	6.8	4.5	3.0	2.4	2.0	1.7
24	8.1	6.0	4.0	3.0	2.5	2.2
26	9.5	6.6	5.1	3.6	3.2	2.8
28	10.0	7.0	5.5	4.0	3.5	3.1
30	9.8	6.8	5.3	3.7	3.2	2.9
32	9.5	6.5	5.0	3.5	3.0	2.8

Source: Hogendoorn *et al.* (1983); Hecht, Uys and Britz (1988).

Under pond-farming conditions, it is advisable to feed the fish at the same time and at the same place each day such that they become accustomed to a particular feeding regime. This allows the farmer to feed on a response basis, which results in less waste and improved FCR (Isyagi *et al.*, 2009b). Under good pond management practices, FCR during grow-out of 1:1 are not uncommon, although this of course depends on the nutrient profile of the feed and the aptitude of the farmer.

3.1 Nutrient requirements and feed production and availability

The nutrient requirements of *Clarias gariepinus* are outlined in Table 6; based on this information various least-cost feeds of variable quality are available on the market throughout the region. In the two largest producer countries (Nigeria and Uganda), catfish feeds are readily available. In Nigeria, there are at least 12 commercial aquafeed producers, and products range from slow-sinking pellets to floating extruded pellets. In Uganda, there is one large producer (Ugachick) that produces a slow-sinking as well as an extruded floating catfish feed (30 percent protein pellets) and, as in Nigeria, there are many small-scale feed producers. All of the commercial feed producers in Nigeria essentially target the needs of catfish farmers. However, specifically formulated and extruded pellets (45 percent protein) for the early rearing stages of *C. gariepinus* are imported from South Africa and elsewhere (Ayinla, 2007).

TABLE 6
Dietary nutrient requirements of North African catfish (10–1 000 g)

Nutrient	Quantity[1]	References[2]
Crude protein (% min)	40–43	1, 2, 3, 4, 5, 6, 7, 8, 9
Least cost/appetite feeding protein requirement	35–38	1, 6
Crude lipid (% min)	10–12	1, 2, 6, 7
Carbohydrate (% recommended)	15–35	1, 6, 7, 10, 11, 12
Digestible energy (min, kJ/g)	14–16	1, 2, 13
Metabolizable energy (min, kJ/g	13	2
Gross energy (min, kJ/g)	22–24	2, 4, 7, 10
Protein to energy ratio (mg/kJ)	22–30	1, 2, 4, 7, 10
Lipid to carbohydrate ratio (g/g)	2.47	6

[1]Units stated in parentheses in column 1
[2]*Source*: 1: Uys (1989); 2: Machiels and Henken (1985); 3: Machiels and Henken (1987); 4: Degani, Ben-Zvi and Levanon (1989); 5: Fagbenro, Nwanna and Adebayo (1999); 6: Ali (2001); 7: Pantazis (1999); 8: Ali and Jauncey (2005b); 9: Ali and Jauncey (2005c); 10: Ali and Jauncey (2005a); 11: Balogun and Ologhobo (1989); 12: Heinsbroek, Van Thoor and Elizondo (1990); 13: Yilmaz *et al.* (2006).

Specifically formulated commercial catfish feeds are only available in certain African countries (i.e. Cameroon, Kenya, Nigeria, South Africa and Uganda) (Hecht, 2007). Extruded floating or slow-sinking pellets are currently only available in Nigeria, South Africa and Uganda. Large-scale, intensive catfish farmers throughout the African subcontinent are currently (2010) still not entirely satisfied with feed quality. It was not possible to obtain a list of ingredients that are used for the feeds except from Ugachick, which uses soy bean, maize, sunflower and wheat products, mukene (silver cyprinid, *Rastrineobola argentea*) fishmeal, unspecified fish oil, vegetable oil and bone meal from Nile perch skeletons. Ugachick in Uganda produces three different feeds for *Clarias*, the proximate composition of which is shown in Table 7. Because of the low protein content of the pre-starter and starter feeds, farmers in Nigeria and Uganda import these feeds from South Africa and elsewhere for the early rearing stages until the fish reach ~12 g (Ayinla, 2007; Rutaisire, 2007; Akinwole and Faturoti, 2007).

TABLE 7
Proximate composition of catfish feeds in Uganda and South Africa

	Crude protein (% min)	Crude lipid (% min - max)	Crude fibre (% max)	Ash (% max)	Ca (%)	P (%)
Ugachick (high protein, pre-starter)	39.9	8.5–9.5	5.5	7		
NutriScience (pre-starter)	45	8	4		3	7
Ugachick (starter)	35	8–10	7	7		
NutriScience (starter)	40	8	4		3	7
Ugachick Catfish (grower)	30	7–8.5	8	7		
NutriScience (grower)	35	7	4		3	7

Source: Information provided by feed manufacturers.

3.2 Feeding in intensive pond farming

Under both of the two intensive pond farming conditions described in sections 3.1 and 3.2 below, profitability depends largely on applying the correct feeding strategy. This implies that the feed satisfies the nutrient requirements of the fish at various sizes, feeding the right pellet size for easy consumption and low wastage, feeding the correct amounts and feeding at the right time(s) each day. When fish are fed correctly, growth rates are good and uniform across the population, FCR are low and pond water quality is optimized (Isyagi *et al.*, 2009b).

3.2.1 Under flow-through conditions

Under intensive pond-farming conditions with water exchange, the fingerlings (~5 g) are stocked into grow-out ponds (0.1 ha) at a density of 100 000/ha and fed according to feeding response and the feeding schedule shown in Table 5. At the beginning of the production cycle and for about two months, the fish are fed three times per day, after which the frequency is reduced to twice a day. The fish population has to be thinned out at regular intervals to maintain a maximum biomass of not more than 40 tonnes/ha, at a water exchange rate of total pond volume once every four days. Under the prevailing thermal conditions, the fish can be harvested at 800 g after 10 months (Uys, 1989).

3.2.2 Without water exchange

The production capacity of ponds under static water management conditions is lower than under flow-through conditions. Under static conditions, using a complete sinking diet, the critical standing crop is around 15–20 tonnes/ha. The critical standing crop is defined as the biomass of fish in the pond when the growth rate begins to slow (Isyagi *et al.*, 2009b). While these yield levels are approximately 50 percent of those achieved under flow-through conditions, they are still extremely high. Isyagi *et al.* (2009b) suggest that fish <10 cm (~6 g) should not be used for on-growing. To obtain a lower mortality rate and a higher level of profitability, they recommend larger fingerlings of around 15 g. Based on a projected harvest weight of 800 g, 24 750 (15 g) fish are required per hectare. This allows for a 10 percent mortality rate during the grow-out period. Isyagi *et al.* (2009b) provide further detailed accounts of the feed choice, management of feed conversion ratios (FCR), record keeping and economic analyses of various feeding strategies under static pond-farming conditions in Uganda. Feed costs make up approximately 60–70 percent of variable costs. Moreover, they (*op cit.*) provide a suite of recommendations for on-farm feed management to ensure freshness and good fish health.

3.3 Feeding in small-scale farming

The farming of catfish by small-scale commercial farmers is becoming more popular in many sub-Saharan countries, including Mozambique, Zambia, Malawi, Kenya and Tanzania. Many of these farmers either cannot afford or do not have access to commercial formulated feeds and hence are forced to use farm-made feeds. For economic reasons, over 90 percent of the feeds used by fish farmers in sub-Saharan Africa are wet or dry feeds made on the farm or by small-scale feed producers (Hecht, 2007). Wet or moist ingredients that are commonly used for catfish feeds in Africa and Asia include chicken entrails, minced poultry farm mortalities, abattoir waste, butchery sweepings, fish market waste (mainly fish entrails), maggots, termites, earthworms, trash fish, hotel or restaurant kitchen waste and live juvenile tilapia. In most instances, these ingredients are mixed with milled oilseed cakes (soy, cotton, sunflower, palm kernel) and relatively inexpensive ingredients such as maize, wheat or rice bran and dried brewery waste.

Many farmers use wet ingredients such as chicken offal as a stand-alone feed and claim to achieve FCR of around 1.3:1 (Ayinla, 2007). Recent trials in Uganda have found that the use of chicken offal results in a high fat content of the meat and unacceptably high abdominal fat deposition (Matsiko and Mwanj, 2008). However, it should be noted that fish with low abdominal fat content are least preferred in many other regions in Africa. There is some evidence to suggest that juvenile catfish fed on mixed moist feeds (34 percent moisture) have poorer performance indices (i.e. weight gain, specific growth rate, FCR, protein efficiency ratio) than juveniles fed on a dry diet using the same ingredients (Fagbenro, 1994; Fagbenro and Jauncey,1994; Fagbenro, Jauncey and Krueger, 1997).

Several farm-made dry feeds are produced, and these range from formulated dry mixes fed to the fish in punctured bags, to moist feed cakes or balls and dry pellets. Preparation and manufacturing technologies are simple – raw materials are milled and cooked (or precooked, e.g. soybeans), mixed into a dough with water and extruded using a meat mincer. The 'spaghetti-like' product is sun-dried or dried in locally manufactured driers and cut or crumbled into appropriate sizes. Anti-oxidants are expensive and not commonly used by small-scale feed manufacturers, such that storage of farm-made feeds is problematic. This is compounded by the absence of proper feed drying facilities. Farmers are advised to mix and prepare only quantities that can be used within a few days. Depending on feeding practices, FCR of 1.1:1 have been reported for some farm-made feeds in Uganda and Kenya (Hecht, 2007).

Because of the high cost of vitamin and mineral premixes, farmers in Africa often use chicken layers mash, which contains minerals and vitamins, as one of the primary components of catfish feeds. In fact, pig and poultry feeds are also often used as alternate feeds for North African catfish throughout the African subcontinent (Liti, MacWere and Veverica, 2002; Nyandat, 2007). Alternative sources of minerals used in Nigeria include bone meal and crushed periwinkle shells (Ayinla, 2007). Gabriel *et al.* (2007) and Hecht (2013) provide succinct overviews of alternative ingredients that have been tested as ingredients for farm-made catfish feeds in sub-Saharan Africa.

3.4 Feeding in intensive tank culture conditions

The on-growing of African catfish under intensive tank culture conditions is somewhat different to pond culture (Oellerman, 1995; Oellermann and Hecht, 1996; Hecht, Oellermann and Verheust, 1996; Akinwole and Faturoti, 2007; Ayinla, 2007). Early fingerling, juvenile and grow-out production schedules are now fairly standardized and are briefly summarized as follows. Post-hatchery fry are stocked at a density of ~25 000/m^3 and on-grown to 4–5 g in ~30 days. At that stage, they are graded into three size classes. The smallest fish are discarded. Fish with an average weight of 4–5 g are then restocked into the tanks at ~8 500/m^3 and reared to 11–12 g in ~30 days. Up to

this stage, the volume of the rearing tanks is generally between 0.5 and 4 m^3, while the tanks used for on-growing in Nigeria and South Africa range in size from 2 to 20 m^3 and are most commonly made of bricks and mortar. The 11–12 g fish are then stocked at 150 to 400 fish/m^3 and reared to market size (420–>850 g). At average temperatures of between 26 and 28 °C, the 12 g fish are grown to 850 g (using 30 percent protein feeds) in approximately 154 days at FCR ranging from 1.1 to 1.6:1 (Oellerman and Hecht, 1996; Akinwole and Faturoti, 2007). Depending on management, production levels range between 107 and 385 kg/m^3/6 month cycle (Oellerman and Hecht, 1996; Akinwole and Faturoti 2007).

Based on information provided by Akinwole and Faturoti (2007), it would appear that high-density tank farming in Nigeria using recirculating systems is still experiencing some teething problems, and these seem to be related to maintenance of good water quality. Nevertheless, comparison of production parameters shows that Nigerian farm results are good and approach the experimental results in the Netherlands (cf. Akinwole and Faturoti, 2007; Eding and Kamstra, 2002 and Eding *et al*., 2006).

Because of the high densities at which the fish are reared, it is preferable to feed the fish five to six times per day. Under high-density tank farming conditions, daily ration tables are at best only guidelines; because of the high cost of feed, farmers are advised to monitor food consumption and to adjust rations on a daily basis depending on the feeding intensity of the fish. A sample of fish is normally weighed on a weekly basis (or every 10 days) to check feed consumption against recommended levels.

Further strategies to reduce feed costs should be developed. For example, Ali (2001) found that alternating periods of restricted feeding (maintenance requirement) for three days and appetite feeding for the following four days is a plausible way in which to reduce feed input cost for this species. However, in a later study, Ali and Jauncey (2004) showed that *C. gariepinus* only shows partial compensatory growth under periods of restricted and satiation feeding.

Feeding of African catfish under intensive tank culture conditions can be done by hand or can be mechanized using demand feeders or compressed air feed distributors. Demand feeders under these conditions are not recommended, as the pendulum is in continuous motion, which may lead to feed losses. Despite the switch to intensive tank culture, very little is known about the way to manage and optimize feed use under these conditions, and there is a clear need to investigate this.

4. CONCLUSIONS

The farming of African catfish in sub-Saharan Africa is a commercial activity (defined as a national production of >1 500 tonnes per annum) in only three countries *viz*. Nigeria, Uganda and Kenya. In all other countries that report production statistics, the activity is best described as marginal. The reasons for this are varied. In South Africa, market resistance is the only impediment; while in many other countries access to information, high cost and availability of capital, inadequate supplies and services and poor infrastructure seem to be the overriding reasons. The technology for the farming of the species at various levels of intensity is, however, very well established. It appears that Uganda has recently become the centre of catfish farming development for food and for the live bait sector.

There have been significant improvements in the aquafeed sector since 2005 (Hecht, 2007), both in terms of quality and supply. Most countries in the region have adequate resources to manufacture appropriate feeds, although the availability and cost of fishmeal and soybean meal or oilseed cake are major constraints in most countries (Hecht, 2007). The general paucity of good-quality aquafeeds in the region is generally a factor of scale. Uganda provides the best example of this supposition. In 2005, commercial aquafeeds were not available in Uganda (Rutaisire, 2007) but now, because of the rapid increase in catfish production, all the necessary feeds (fry,

fingerling and on-growing feeds) inclusive of floating extruded feeds are manufactured locally. It is however unknown what proportion of the Ugandan catfish production is reared on formulated and/or farm-made feeds. Although it is reported that farmers in Nigeria and Uganda use high-protein imported feeds during the nursery phase, it is anticipated that more appropriate feeds will also soon be manufactured in all major catfish-producer countries.

Commercial feeding schedules during the nursery and on-growing phases have also been fairly standardized. Live food (mainly *Artemia*) is generally used for the first five to six days of exogenous feeding, after which the juveniles are weaned onto dry feeds. During the early and late on-growing phases in ponds, the fish are fed by hand to satiation at the same place and time; this reduces wastage. Under high-density tank farming conditions, the fish are either fed by hand or through the use of demand feeders. The use of the latter is considered wasteful, and further research is required to optimize feeding practices in tanks under high-density conditions.

Subsistence farming of catfish under polyculture or monoculture conditions using single ingredient feeds will remain marginal and make insignificant contributions to food security and national production figures.

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Shrimp feed management: issues and perspectives

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ABSTRACT

This review commences by briefly describing the scale and importance of marine shrimp within the global aquaculture sector. Typical farming and feeding practices for shrimp grow-out production are summarized and the importance of good on-farm feed management is stressed. Guidelines on feed handling, storage and feeding are provided. The review concludes with a summary and some recommendations for future research.

1. INTRODUCTION

The shrimp aquaculture sector represents one of the most lucrative and fastest growing segments of the global seafood industry. Valued at over US$16.6 billion, global farmed shrimp production was estimated at nearly 3.78 million tonnes in 2010, with production increasing over three-fold from 1.1 million tonnes in 2000, and growing at an average annual rate of 14.5 percent since 1950 (FAO, 2012). Moreover, the whiteleg shrimp (*Litopenaeus vannamei*) was ranked first in 2010 in terms of total farmed fish and crustacean production by value, at US$11.23 billion (FAO, 2012).

2. SHRIMP SPECIES AND COUNTRY PRODUCTION

In 2010, the bulk of global shrimp production was restricted to the culture of two major species, the whiteleg shrimp (*L. vannamei*; 2 720 929 tonnes or 72 percent of total production by weight) and the black tiger prawn (*Penaeus monodon*; 781 582 tonnes or 21 percent). Other minor cultivated species included, the kuruma prawn (*P. japonicus*; 56 739 tonnes or 1.5 percent), the fleshy prawn (*P. chinensis*; 45 339 tonnes or 1.2 percent), the Indian white prawn (*P. indicus*; 27 325 tonnes or 0.7 percent) and the banana prawn (*Fenneropenaeus merguiensis*; 19 821 tonnes or 0.5 percent) (FAO, 2012).

Shrimp aquaculture production is reported to the Food and Agriculture Organization of the United Nations (FAO) by 59 countries, with the major producing countries in 2010 being China at 1 448 019 tonnes or 38.4 percent of total global production by weight, followed by Thailand (566 796 tonnes or 15.0 percent), Viet Nam

(478 700 tonnes or 12.7 percent), Indonesia (379 327 tonnes or 10.1 percent), Ecuador (223 313 tonnes or 5.9 percent), India (112 100 tonnes or 3.0 percent), Mexico (104 612 tonnes or 2.8 percent), Malaysia (87 202 or 2.3 percent), Brazil (69 422 tonnes or 1.8 percent), and the Philippines (55 899 tonnes or 1.5 percent) (FAO, 2012).

3. FARMING PRACTICES

Farming practices currently employed for shrimp vary widely both between and within countries, which vary according to the species farmed, the financial resources of the farmer and the production method employed. In general, shrimp production methods can be divided into three basic types depending upon the shrimp stocking density and the external inputs received over the production cycle; these range from extensive non-fed pond-based farming systems, to semi-intensive compound feed-fed pond-based farming systems, to intensive compound feed-fed pond and tank-based farming systems (Table 1). It follows therefore that the feeds and feeding methods employed by shrimp farmers also vary considerably between and within countries. This is in marked contrast to commercial poultry and salmon farming operations, where for the most part animals are raised within intensive production systems at similar densities and culture environments and fed nutritionally complete diets over the duration of the production cycle.

TABLE 1

Farming and feeding strategies used for growing shrimp from postlarvae to market size

	Extensive outdoor farms	Extensive outdoor farms	Semi-intensive outdoor farms	Intensive outdoor farms	Intensive indoor farms
Shrimp species	*Litopenaeus vannamei* *Penaeus monodon* *P. chinensis* *P. indicus*	*L. vannamei* *P. monodon* *P. chinensis* *P. indicus*	*L. vannamei* *P. monodon* *P. chinensis*	*P. monodon* *L. vannamei* *Farfantepenaeus duorarum* *P. aztecus* *Fenneropenaeus meguensis*	*P. monodon* *L. vannamei* *P. indicus* *P. esculentus*
Rearing units	Large earthen ponds or enclosures up to 100 ha	Large earthen ponds or enclosures up to 100 ha	Earthen ponds of 1–20 ha	Earthen ponds of 1–20 ha	Plastic or concrete tanks of 100–1 500 m^3 or lined ponds of >1 ha
Water exchange (percent per day)	Tidal or pumping, less than 5%	Tidal or pumping, less than 5%	Pumping, 5–20%	Pumping, 5–40%, although not always as in closed culture systems	Pumping, 2–5%, although not always as in closed culture systems
Stocking rate	Usually less than 5/m^2	Usually less t han 5–10/m^2	12–25/m^2 10–20/m^3	40–140/m^2 25–75/m^3	200–2 000/m^2 120–750/m^3
Aeration	None	None	Partial/continuous aeration, particularly at end of culture	Partial/continuous aeration, particularly at end of culture	Continuous aeration, particularly at end of culture with oxygen
Labour input (persons/ha)	Usually >0.1	Usually >0.1	Low to moderate, 0.1–0.5	High, 0.4–2	High, 1–3
Feeding regime	None	Fertilization & /or complete/ supplementary diet feeding	Fertilization &/or complete/ supplementary diet feeding	Fertilization &/or complete/ supplementary diet feeding	Fertilization &/or complete/ supplementary diet feeding
Feed conversion ratio1	–	0.9–1.3	1.2–1.75	1.4–2.0	1.4–3.0
Head-on shrimp production (kg/ha/year)	>500	>1 000	1 000–3 000	10 000–40 000	40 000–340 000
Production cost (US$/kg live shrimp)	1.00–2.00	1.70–2.50	2.20–3.30	3.50–5.00	4.00–7.50

Note: [1] Following enquiries by the editors, the authors of this review have confirmed that the figures shown in this line of the table are FCR.

Source: Tacon, Nates and McNeil (2005).

4. IMPORTANCE OF GOOD ON-FARM SHRIMP FEED MANAGEMENT

For the purposes of this paper, 'on-farm shrimp feed management' covers all those activities conducted by shrimp farmers and their staff related to the handling, storage and application of shrimp feed on the farm; shrimp feeds include commercially manufactured feeds, farm-made feeds and/or live/natural food items.

In general the nutritional performance of a shrimp feed depends upon five interconnected factors (Figure 1), namely:

- the nutrient content and composition of the diet being fed;
- the physical properties and water stability of the diet being fed;
- the transportation and storage of the diet prior to feeding on the farm;
- the feeding method employed for feed application and usage on the farm; and
- the farming system, stocking density, water management and availability of natural foods.

Of these, the commercial shrimp feed manufacturer has direct control over the first two factors, while farmers and their staff have direct control over the last three. It follows, therefore, that the eventual nutritional performance and economic success (or failure) of a shrimp feed is dependent upon a close collaboration and partnership between the feed producer and the farmer and his staff. Shrimp feeds and feeding usually represent the largest operating costs (typically between 40 and 60 percent) of most semi-intensive and intensive farming operations (Molina, 2009).

The importance of good on-farm shrimp feed management can be seen from the reported variation in feed conversion ratios (FCR) observed between 174 different black tiger shrimp farms fed the same commercial shrimp diet in Thailand (Figure 2). FCR and observed shrimp production costs ranged from 1:1 to 2.6:1 and US$1.2 to 2.60/kg shrimp harvested, respectively. These variations in shrimp feed performance show the wide variations that commonly exist between individual shrimp farmers, depending upon the farming and feed management practices employed.

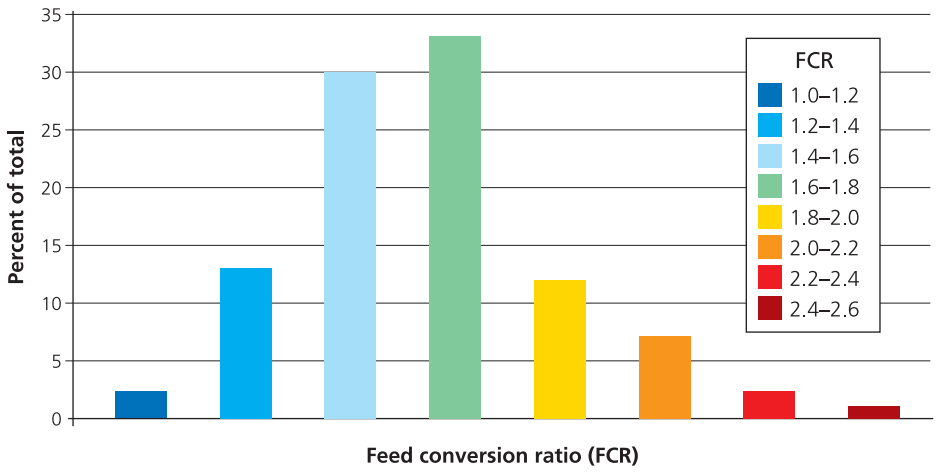
FIGURE 1
Key factors influencing shrimp feed performance and success

Source: Modified from Tacon (1993).

It is estimated that the global average farm eFCR (economic feed conversion ratio) for shrimp and salmon in 2008 was 1.5:1 and 1.3:1, respectively; 5.06 million tonnes of shrimp feed and 2.04 million tonnes of salmon feed being consumed for the production of 3.40 million tonnes of shrimp and 1.57 million tonnes of salmon in that year (A.G. J. Tacon, unpublished data). Thus shrimp farming has a poorer feed conversion efficiency than salmon farming. The difference in eFCR between these two major farmed species groups is even more remarkable if one considers that it usually takes 18 months to grow a salmon from egg to market size (typically 3.5–4.5 kg), while shrimp have a much shorter culture period (5 to 7 months) and a much smaller market size (typically 15–30 g), depending upon the species farmed.

Farmed salmon are almost exclusively reared at high densities within open-water cage enclosures and fed high-lipid nutrient-dense feeds (Crampton *et al.*, 2010).

FIGURE 2
Variation in feed conversion ratio in 174 black tiger shrimp farms using CP shrimp feed in Thailand



Source: Tacon (1993).

However, shrimp differ from salmon and other carnivorous fish species in several important aspects of biology and feeding habits, namely:

- Farmed shrimp are scavenging, opportunistic feeders in their natural environment and under farming conditions are also able to harness food particles suspended in the water column (e.g. phytoplankton, zooplankton, microbial flocs, organic detritus, etc.) and food organisms living on the pond bottom (e.g. plant and animal biota), in addition to applied artificial feeds (Nunes, 2009); and
- Farmed shrimp have poorly developed eyes and vision, and consequently reply primarily on chemical attraction and stimulation to locate and consume their food, including artificial feeds. As a direct consequence, artificial feeds for shrimp generally have to remain immersed in water for prolonged periods of time (typically for several hours) prior to being externally masticated and then consumed (Obaldo and Masuda, 2006).

The significance of the above is that special consideration must be given to feed formulation and feed manufacture when formulating and producing shrimp feeds, including: the need to tailor dietary nutrient levels to the intended culture system and the endogenous availability of natural food organisms; the need to produce artificial feeds that are both physically water stable and chemically attractive and palatable to farmed shrimp. Although outside the scope of this paper, both of these factors have very important implications for the ultimate performance and success of formulated shrimp feeds (Figure 1).

5. GUIDELINES FOR GOOD ON-FARM SHRIMP FEED MANAGEMENT

5.1 Shrimp feed handling and storage

Shrimp feeds are composed of formulated mixtures of ingredients containing 40 or so essential nutrients (e.g. proteins and amino acids, fats and fatty acids, carbohydrates and sugars, minerals and trace elements, and vitamins) that are prone to deterioration and loss or destruction upon prolonged storage prior to feeding.

Nutrient losses and destruction may result from the prolonged exposure of finished feeds to unfavourable storage conditions on the farm, either due to inadequate shelter and protection of the feed from the natural elements (light, heat, humidity, air and water) and/or due to microbial/pest infestation (bacteria, fungi, insects, rodents). As a general rule, feeds should be stored under cool well-ventilated conditions and

not subjected to direct exposure to the sun and rain, including extremes of heat and humidity. Under the above ambient conditions, feed shelf life should be not more than two to three months under tropical/warm (20–30 °C) storage conditions and not more than four to six months under temperate/cold (10–20 °C) storage conditions. Whenever possible, formulated feeds should be stored in a dedicated roofed storage facility and the feeds used on the farm on a 'first-in – first-out' basis.

5.2 Shrimp feeding regime

In contrast to terrestrial farm animals and farmed fish where compound feeds can be fed on a visual basis according to the appetite of the animals or to a preset feeding level, pond-raised shrimp are not directly visible to the farmer during feeding, and as such, animals have to be fed 'in the dark'. As a consequence, compound shrimp feeds are usually fed by farmers at a fixed daily rate based on shrimp body weight and an estimate of the total shrimp biomass present in the pond or tank, with the feed usually being applied by hand or mechanically several times daily over an 8 to 12 hour working day.

However, there are practical difficulties in accurately determining the total shrimp biomass within commercial grow-out ponds, which typically vary in size from <1 000 m² to >20 ha (Table 1). In estimating dietary feeding levels for a particular diet and dietary nutrient density, farmers are usually forced to feed their animals on a targeted/expected weekly growth response (or to attain a certain final shrimp target weight over a preset culture period). This practice comes with a consequent risk of over- or under-feeding, environmental pollution (due to over-feeding), and suboptimal FCR and growth.

For example, under practical farming conditions, the feeding response, feed intake (expressed as percent shrimp body weight), feed utilization efficiency and growth of shrimp vary with numerous biological, environmental and human factors, including:

- *Shrimp body weight*: compound feed intake decreases with increasing body weight and decreasing metabolic rate over the culture cycle (Table 2).
- *Water temperature*: compound feed intake and growth increases with increasing water temperature up to an optimum level (typically between 29 and 31 °C for *L. vannamei* and *P. monodon*), with water temperatures - and consequently dissolved oxygen levels - sometimes varying widely over a working day depending upon the culture system used and season.
- *Natural food availability:* compound feed intake increases with decreasing natural food availability within the culture system (which includes natural foods present within the water column and/or pond bottom), with pond bottom natural food availability generally decreasing with increasing shrimp stocking density, increasing shrimp weight and increasing total shrimp biomass over the culture cycle.
- *Compound feed formulation and nutrient density:* feed intake and growth are dependent upon the water stability, palatability and nutrient composition of the diet fed; the better the water stability and palatability and the higher the nutrient content of the diet fed, the higher the potential feed intake and feeding response of the diet (but not always).
- *Shrimp feed application method, including frequency and timing of application, and feed consumption monitoring method:* compound feed intake and growth are usually easier to control and monitor during daylight hours within smaller hand-fed intensively stocked ponds (as compared with larger semi-intensively stocked ponds), with optimum feeding frequency and timing of application being dependent upon the size of the shrimp and the nutrient density of the diet fed, and generally being highest for small, rapidly growing shrimp, and thereafter decreasing with increasing shrimp size.
- *Technical knowledge and expertise of the feeding technician:* as a general rule, feeds are usually administered within larger farms by workers who receive the lowest or minimum

salary, usually with little or no incentives for increased worker incomes through achieving improved feed performance and shrimp growth given by farm owners.
- *Shrimp moult cycle, lunar cycle phase and feeding behaviour:* feed intake and growth are dependent upon the physiological state and condition of the shrimp, with feed intake usually decreasing immediately prior to and during the moulting cycle and natural feeding activity being highest during non-daylight hours.
- *Shrimp health and wellbeing, including ecosystem health:* feed intake and growth are generally lowest for stressed and diseased shrimp, including those in polluted and environmentally stressed pond ecosystems.

TABLE 2
Suggested feeding rates for Pacific white shrimp fed a 35 percent crude protein and 8 percent crude lipid diet at varying water temperatures

Shrimp body weight (g)	Feeding rate (percentage of estimated shrimp biomass)		
	21–24 oC	24–28 oC	28–32 oC
1–3	8.0	6.0	7.0
3–5	7.0	5.0	6.0
5–7	6.5	4.5	5.5
7–9	6.0	4.0	5.0
9–11	5.5	3.5	4.5
11–13	5.0	3.0	4.0
13–15	4.5	2.5	3.5
15–17	4.0	2.5	3.0
17–30	3.0	2.0	2.5

Source: Tacon *et al.* (2002).

In view of the above variables, it is perhaps not surprising, as noted in Section 4, that the observed average shrimp eFCR (eFCR includes mortality, and refers to the relative quantities of feed fed per unit of fish or shrimp harvested) in 2008 was estimated to be about 1.6:1 (as compared with 1.3:1 for farmed salmon). Sadly, to date, dietary feeding regimes have more often than not been related to the convenience of the feeding technicians or farm workers during their working day, rather than to the species-specific behavioural and nutritional feeding requirements of the cultured shrimp species.

6. SUMMARY AND CONCLUSIONS

6.1 Summary

Shrimp aquafeed management aims at making available to the animals the best quality, formulated aquafeed in the proper amounts and at the right times and locations. Feeding methods and techniques are as important as feed quality and are closely interdependent. Feeding practices must be continually modified and adapted to account for natural and induced changes in feeding activity and preferences as the animals grow and/or environmental conditions change. Knowledge of shrimp behaviour and feeding habits and a continuous feedback on pond environmental parameters and shrimp population are factors critical for successful feed management.

Management of formulated aquafeeds is a sequential process that is only as strong as its weakest link. As it did some 30 years ago at the dawn of the industry, it still includes feed selection, handling and storage; feed application methods; and feeding regimes

and adjustments to feeding rates. Often, observed differences in performance between different feeds are the result of the management received and not a result of differences in formulation, ingredients or manufacturing. If not properly managed and fed, the best formulated aquafeed will generally be not much more than expensive fertilizer.

Adequate feed management methods are critical for efficient production and to minimize environmental impacts. Shrimp production systems and their feed management must be considered together and require an understanding of the biological aspects of the targeted species and the chemical and biological processes that control water and bottom quality, and require continuous system monitoring and feedback to provide appropriate and timely inputs and adjustments. Effective practices will produce maximum shrimp growth and survival concurrent with the lowest feed conversion with minimum impact to effluent quality. Inadequate feed management will lead to suboptimal production, can promote the onset of various diseases and can lead to water quality-related problems. Several sequential steps are involved in proper feed management: feed selection; reception, storage and handling; application methods; and feeding regimes. Choosing when to feed requires the determination of shrimp activity patterns, feeding frequency and time (subject to change with geographical location, species, age, size, stocking density, season, unusual environmental conditions and other stimuli).

Calculating feed rations involves estimating survival, population size and biomass, size distribution and natural food availability. Adjusting feed input involves population sampling and monitoring of various water parameters. Proper feeding strategies must consider physiological processes that affect feed intake and digestion in the targeted shrimp species. These include relationships between feeding activity and circadian rhythms, gastric evacuation times, moulting cycle stage, etc. Shrimp are bottom feeders, and it is difficult to estimate feed consumption rate unless feed trays or lift nets are used. For many years, trays have been the best tool available to manage and adjust feed inputs and prevent under- and over-feeding. Inefficient management methods commonly include inadequate handling and storage practices for both bulk feed storage at farms and after feed distribution to pond side for daily feedings. Ineffective practices often include applying feed during times convenient for employees but not necessarily optimal for shrimp and underestimating the importance of proper training, remuneration and motivation of feed management personnel.

The development and use of compound aquafeeds has been a major factor in the global expansion of shrimp farming, and efficient feed management is critical to maintain and improve the financial and environmental viability of the industry. There is still much potential to improve and optimize responsible and efficient feed management practices that can be species-, area- and even season-specific, to optimize production efficiency, minimize environmental impacts, promote maximum biosecurity, and promote cost-efficiency and profitability. Phase-to-phase feeding programmes must be designed to target the best feed nutrient profile and feed presentation at a specific culture stage, environmental and rearing condition. Culture challenges such as disease, poor water quality, and high stocking densities can be minimized with the proper feed design. On the other hand, feeds must be aligned to account for the availability of natural food in ponds in order to spare critical and expensive nutrients, such as proteins, vitamins and minerals.

6.2 Conclusions

The bottom line in any commercial farming operation is profitability, and, since feeds normally represent the greatest single cost, it follows that the successful development of appropriate shrimp feeds and on-farm feed management protocols is of paramount importance to the farmer. Moreover, it cannot be over-emphasized that shrimp feeds and feeding is a *chain* of linked interdependent processes in which feed formulation and nutrient content, for example, is only one of five different links. However, it is

clear that, like any chain of linked processes, the strength and ultimate performance of a shrimp feed and feeding regime will only be as good as the weakest link. In the past, on-farm feed management has usually been one of the weakest links in the chain.

Areas of priority for further research concerning shrimp feed management include:

- improving knowledge of the biological and chemical processes in production systems that affect animal behaviour, including feeding;
- improving knowledge of the physiological processes that affect shrimp feed intake and digestion;
- maximizing the use of natural productivity, nutrient recycling and retention in shrimp flesh; and
- optimising overall management of production systems, of which feed management is only a component in a sequential and additive process from stocking to harvest.

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On-farm feeding and feed management: perspectives from the fish feed industry

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ABSTRACT

The growth of global aquaculture and its development from small to large scale across a wide range of species is well documented. As the global human population grows and logistics improve, the demand for seafood (wild and farmed, fresh, processed and frozen) is forecast to grow further. Seafood is a healthy part of a balanced diet and eating seafood is also associated with a decrease in lifestyle diseases, which has led to professional recommendations to eat yet more. It is clear that aquaculture will have a major role in meeting this increased demand for seafood. However, in satisfying this demand, there must be a further shift from extensive to intensive-scale operations. For a variety of practical reasons, this intensification will mean a change from using waste or farm-made feeds to industrially manufactured pellets for the farming of fish and crustaceans. Commercial fish feed companies are best placed to provide such formulated pellets, but there is a strong pressure to optimize the use of resources while providing the lowest cost of production to the farmer. Formulated feeds cannot compete with farm-made feeds on unit price. However, nutrient composition and technical properties should be superior in commercial feeds, and this will have an important impact on production efficiencies.

Feed companies have a strong responsibility to manage and develop these properties so that the feed delivered has the potential for maximum output (e.g. growth, survival, quality, efficiency). However, on-farm feed storage and management is also critical to maximizing the value of the resources used. Storage at farm sites must be sufficient to maintain the delivered feed quality (e.g. dry and secure). Feed management is primarily the responsibility of the farmer. On the day of feeding, the feed used should fit the species and size of animal. The amount of feed given should be controlled and distributed evenly and effectively across the unit to allow feeding opportunity to all animals. Feed delivery should also be

changed according to environmental conditions (e.g. diurnal water quality fluctuations). Farmers must feed with particular attention to the health status and appetite of the stock. Feed companies should be in a position to advise the farmers on best practice and to help them monitor their performance, especially if the use of manufactured pellets is new (e.g. via use of feeding tables, size change recommendations). This process can be assisted by other resources such as training, local government schemes and development aid projects. Benefits that come from the use of formulated quality feed are best achieved when the farmers optimize their management practices. Close collaboration and long-term partnerships between feed companies and farmers are strong tools to provide efficient production and the best use of resources in the growth of healthy and nutritious aquaculture species.

1. INTRODUCTION

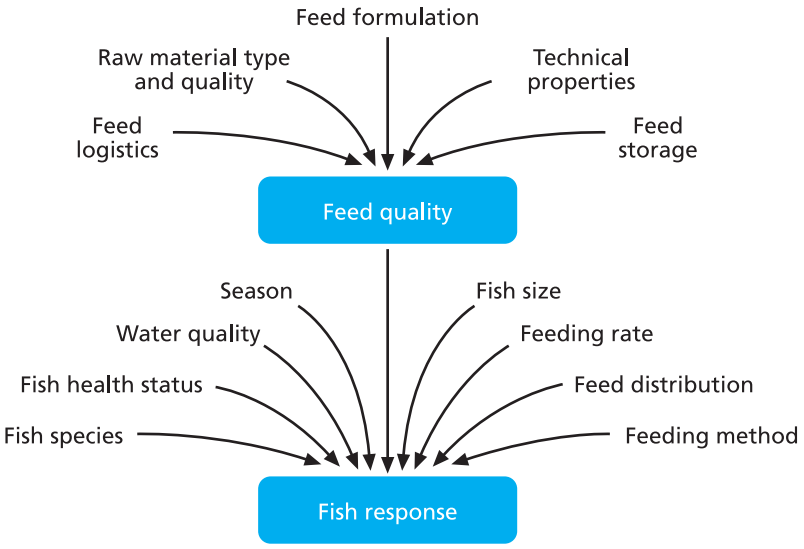
As global aquaculture production increases to meet the increased need for food and especially seafood, there is an increasing demand for feed supply. Fish farming is increasing in volume, particularly in Asia, where there are good environmental conditions for aquaculture (including warmer water temperatures and more land availability) as well as a large and growing local market. There has also been a tendency to intensify production, adding feed to units, increasing the number of animals per unit and attempting to grow them faster.

Due to the high conversion ratio of feed into final product (whether it is fish or crustaceans), the demand for feed has increased faster than the production of the aquatic animals. However, as the feeds used vary greatly between species and farming systems, it is very hard to generalize, although it is obvious that feed is the single greatest resource being added to the farm and also the single greatest cost to farmers. Indeed in systems where farmers make very little investment in labour, equipment, seed and medication, feed can account for up to 80 percent of the cost of production. This makes it essential for farmers to focus on feed controls in order to get the most from the feed they buy and to choose the most appropriate feed for their production initially.

Feed management and on-farm practices relating to feed are therefore an essential part of managing not only the economics of the farm, but also the flow of nutrients from the raw materials into the fish. The final product should be available in an edible and attractive form to humans. There is a concern that many aquaculture practices make inefficient use of feed resources. This can be caused by many factors, which will be discussed in this paper; some examples are given in Figure 1.

The purpose of this paper is to add the perspective of the commercial feed manufacturer to the review of on-farm feeding and feed management methods. The goal is to achieve the best results from a given amount of resources in terms of healthy fish growth into edible flesh. The discussion is quite general due to the necessity of covering a wide range of species, environments and farming methods; however, there are some common threads that are applicable to all farming situations. Lessons learnt from the farming of salmonids are often cited in this paper, as this is the group of fish where the greatest number of publications can be found, given the research focus in the last 20 years. However, knowledge relating to other species is growing and specific details will be added in the future. Throughout this paper, the discussion is relevant to all farming methods for fish and crustaceans; thus in order to simplify presentation, the word ‘fish’ is used when referring non-specifically to cultured stocks.

FIGURE 1
Schematic diagram showing some of the factors that can impact on feed quality and how the fish responds to that feed



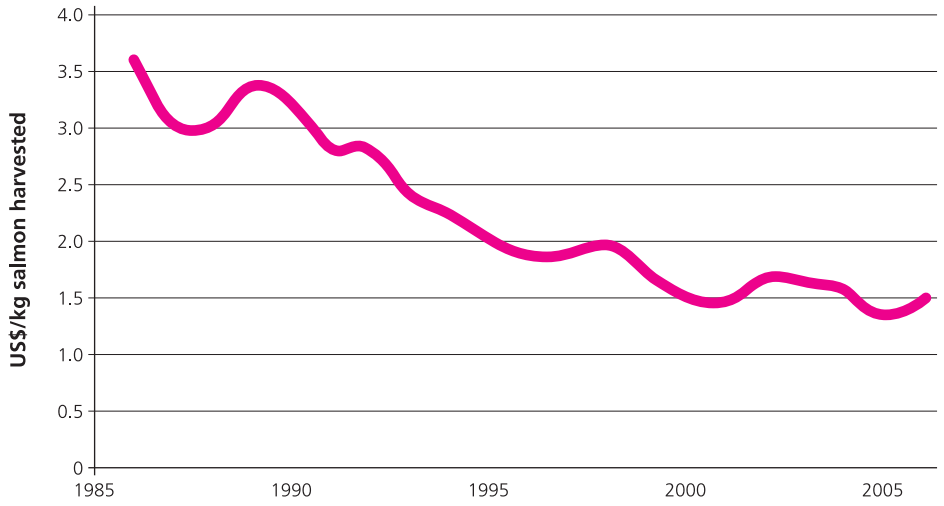
Source: This review.

2. WHAT CAN BE ACHIEVED?

In order to understand the possibility of managing feed resources most efficiently, it is useful to take a look at the successes seen in Atlantic salmon (*Salmo salar*) farming. These are covered in detail by Kaushik (2013), but will be briefly mentioned here.

Atlantic salmon farming started in the 1970s, and at first the feeds were very simple, often made on-farm. As nutritional research into the requirements of the fish was carried out and farmers switched to pelleted feeds, the efficiency of the feeds increased – less feed was required to grow more fish. Technical developments in feed extrusion and coating technology supported

FIGURE 2
The relative feed costs of Atlantic salmon raised in Norway from 1985 to 2006 (cost of feed per kg of salmon raised)



Note: Allowing for inflation and exchange rates, based on the Norwegian Kroner value of 2008 and using an exchange rate of US$1 = 5.70NOK.
Source: O.J. Torrissen, Institute of Marine Research, Bodø University College, Norway.

these improvements until, by the mid-2000s, diets could be produced with high protein (40 to 50 percent) and high oil (up to 40 percent). Such diets are still used today and possibly represent the maximum capability of technology to hold together such a balance of nutrients. From this point on, nutritional work has really focussed on how to make the same dietary specifications more economically, although performance improvements have also been found through further improved knowledge on nutritional requirements. The limited future supply of fish-based raw materials has also been a driver for the development of alternative raw materials.

In contrast, once the feed performance per se (as determined by its nutritional and technical properties) stabilized, farmers found that they had to manage this feed more effectively in order to be more efficient. Farmers quickly established management systems that developed greater efficiencies, as measured by the total amount of feed fed converted into fish harvested at the end of the cycle. It is this combination of improved feed quality and improved feed management that allows the best use of resources to be achieved on-farm (providing, of course, that the health status of the fish allows good growth as well). The clear impact of this can be demonstrated by examining the reduction in relative feed costs from 1985 to 2006 (Figure 2). With such improved feed management, farmers are again able to find more subtle benefits of the feed, especially where there are disease issues that can be alleviated by dietary means.

3. TOOLS TO MEASURE FEED AND FEEDING PERFORMANCE

In order to determine how well feeds are performing practically, farmers require simple yet efficient tools.

3.1 Economic feed conversion ratio[1] (eFCR)

The most commonly used tool is the economic feed conversion ratio (eFCR), which can simply be described as the weight of feed supplied to the unit, divided by the increase in fish biomass from stocking to harvest:

$$eFCR = Weight_{Feed}/(FW_{Fish} - IW_{Fish})$$

Where:
$Weight_{Feed}$ = total weight of feed given to the unit (kg),
IW_{Fish} = Total weight of live fish at the start of the period (kg), and
FW_{Fish} = Total weight of live fish at the end of the period (kg)

This basic calculation effectively integrates many different factors into just one number, comparing the weight of resources (feed) supplied with the incremental weight of resources (fish) taken out at the end. In order to calculate this, the farmer needs to know how many tonnes of feed were delivered to the farm for these fish, the total initial weight of live fish and the total final weight of live fish. As such, the equation takes account of the mortalities and escapes that may occur during the cycle – which can be important losses of resources.

The eFCR takes into account the quality of the feed put into the bag by the manufacturer (nutritionally and technically, in that broken feed and dust will probably not be eaten by the fish). Feed type is particularly important here, as dry, extruded feeds are much more efficient than wet feeds on a weight for weight basis (but is much closer in efficiency if wet weight values are corrected to dry weight).

[1] Ratio between the dry weight of feed fed and the weight of yield gain. Measure of the efficiency of conversion of feed to fish (e.g. an FCR of 2.8:1 means that 2.8 kg of feed is needed to produce one kilogram of fish live weight). Two additional terms are used by the farmer, the biological FCR (bFCR) and the economic FCR (eFCR). bFCR is the net amount of feed used to produce one kg of fish, while the eFCR takes into account all the feed used, meaning that the effects of feed losses and mortalities, for example, are included (FAO, 2010).

The eFCR also covers what may happen to the feed once it has arrived on the farm, how effectively it is fed to the fish and how well the fish eat and digest it (thus it encompasses not just the nutritional capability of the feed, but also the health status of the fish). Factors well outside the control of the feed quality can affect this ratio – fish disease and mortalities have strong leverage, for example, as do the environmental conditions in which the fish are raised.

For a farmer to track the best use of resources, eFCR is a very strong tool. It is also an excellent tool for feed companies to monitor the performance of their feeds as used in the field. Professional feed suppliers will have standard expectations for their feeds developed from experiments or benchmarking work with their customers. Variance from these expectations indicates that farmers have an opportunity to optimize their performance, although it does not indicate what may have caused the variation. In order to reduce (improve) the eFCR, farmers should then follow a series of corrective actions as detailed in section 9.4.

The eFCR differs from the so-called biological FCR (bFCR) in that it accounts for all feed given to the fish, whether eaten or not. The bFCR accounts only for feed eaten and as such is nearly impossible to measure in a practical farming system. It also accounts for the weight of any mortalities during the cycle, which in practice represents a loss of resources. bFCR can be measured in research systems and is frequently used here to gauge the efficiency of the feed itself – removing problems of poor feed management.

$$bFCR = Weight_{Eaten}/(FW_{Fish} - IW_{Fish} + W_{Morts})$$

Where:
$Weight_{Eaten}$ = Total weight of feed eaten by the fish (kg),
IW_{Fish} = Total initial weight of fish (kg),
FW_{Fish} = Total final weight of live fish (kg), and
W_{Morts} = Total weight of dead fish over the cycle (kg)

The bFCR is commonly reported after trials performed in tanks or aquaria, where it is possible to collect uneaten feed and so determine exactly how much feed was eaten. Scientific papers and some commercial trials will commonly report this number as it relates to the feed directly and can be controlled carefully within the test environment. Trials that cannot collect uneaten feed report eFCR, which cannot differentiate between poor feed and poor feeding techniques – but simply report the fish growth on the resources put into the water. Therefore, in all practical cases, the bFCR of a feed will be lower than or equal to the eFCR.

For the purposes of this paper, which aims to focus on practical ways of improving the conversion of feed given into fish for consumption, the eFCR is the most relevant calculation. The bFCR is relevant when trying to compare the direct nutritional qualities of two feeds, which is just one part of the whole picture for farmers.

3.2 Growth rate

Another good tool for farmers to monitor performance is measurement of the growth rate of their fish. Coupled with survival, this gives a perception of how well the fish are coping in their environment. Stressors, poor feed quality, impaired health status and bad feed management will reduce the growth rate and most likely the survival to some degree. However, it should be noted that the maximum growth rate is unlikely to be achieved at the lowest eFCR – the highest growth rate tends to be achieved at the expense of some feed efficiencies; however, a faster growth rate may give a better economic return if the market conditions are right (e.g. high sales price for the fish and relatively low price for the feed).

Growth rate can be measured simply as the weight gain over a period of time. Farmers can plot the weight of their fish against time on a simple graph and monitor this. However, fish of different weights will have a different total gain per day. In order to compensate for this, the specific growth rate (SGR) expresses growth as weight gain per day as a percent of the initial weight. As temperature also has an important impact on growth rate, the thermal growth coefficient (TGC) makes an allowance for this, so that comparisons can be made between growth at different water temperatures.

$$SGR = [(FW_{Fish}/IW_{Fish})^{1/n} - 1] \times 100\%$$

$$TGC = [FW_{Fish}^{1/3} - IW_{Fish}^{1/3})/(n \times t)] \times 1\,000$$

Where:
IW_{Fish} = Initial Weight (g)
FW_{Fish} = Final Weight (g)
n = number of days between initial and final weights
t = average temperature in °C

For farmers to get the most out of their growth data, they should be able to compare the growth of their own fish, as measured by regular fish samplings, with a standard curve that is relevant to the feed and environment in which they are growing their fish. Such a curve could be supplied by a feed company, researchers or even by historical data from the farm. Gross deviations below the standard indicate a problem that needs to be identified and addressed. Deviations above the standard curve can indicate that the fish are capable of better performance than the standard, and practices and expectations should then be updated.

3.3 Cost of production

A critical economic tool for the farmer is the total cost of production. This takes into account all of the cost inputs to the fish at the present time (this could be at mid-cycle or at harvest time). The strength of this calculation lies in its ability to give value to positive inputs, although it can be difficult to determine which factors have given value and which have reduced it. For example, a feed with a high nutritional quality may be more expensive per kilogram than a poor feed. However, if properly used, the eFCR achieved by the use of the expensive feed will be lower and the fish will grow faster. Under stressful conditions, such as a disease, the higher quality feed will also reduce the impact of the stressors, perhaps through reducing the impact on growth rate or even by reducing mortalities.

At the point of harvest, the farmer has to be most concerned with the cost of production. This, compared to the sales price, determines the margin that will be made from growing the fish. Short-term costs may have long-term benefits – but the farmer must also be able to find such benefits. Factors that the farmer has to include in these calculations, as they are major drivers of the total cost of production, are:

- cost of fish at input;
- cost of mortalities and escapes;
- total cost of feed;
- cost of sick fish, medication and other chemical treatments;
- cost of labour and infrastructure;
- cost of energy; and
- financial costs incurred until fish are sold after harvest.

It is interesting to note how the factors are interlinked in many cases. The costs of the fish at input are obvious, as are the costs of feed. However, fish at input may be cheap for a reason (such as a disease) and so may have long-term implications on the total cost of production. Similarly, cheap feed may have limited nutritional properties, resulting in slow growth, high eFCR (so more feed has to be bought) and consequences relating to fish health through poor nutrition.

The costs of mortalities and escapes are often not quantified, but resources have been given to these fish, which were then lost as potential value to the farmer. The cost will increase if the mortalities or escapes occur in larger fish, as more resources have been put into these fish. Sick fish grow more slowly, which increases the time before they can be sold, as well as having a poorer feed conversion. They will also require medication, another obvious expense. The total cost of labour and energy increases the longer the fish are kept so, again, a slow growth rate will impact this cost.

All of these costs have to be paid before the fish are harvested and sold, which is when the farmers will hopefully recoup their money. However, in the interim farmers often borrow money, which involves an interest charge – again, the shorter the growing period, the less interest the farmer will have to pay. These costs must be balanced against the sales price and against each other in order to maximize profits.

3.4 What affects feeding performance?

The efficiency with which fish convert their feed into body weight (ideally edible tissues), as this is the resource farmers should be most interested in producing, can be affected by a wide variety of factors, which farmers should seek to gain control over. The issues fall into the following broad categories:

- feed manufacture;
- logistics and storage;
- on-farm handling; and
- feeding methods, timing and quantity.

These will be addressed in greater detail below, together with ways in which farmers can seek to improve their feeding performance results.

4. FEED MANUFACTURE

The issue of feed preparation sets the intrinsic quality of the feed that the farmer will use. If the feed is of poor quality from the start, it will not enable rapid fish growth, no matter how well the farmer uses it. However, high-quality feed can be used badly, wasting the resources.

4.1 Fish requirements versus dietary specifications

Fish will have a certain biological requirement for nutrients in order to make healthy, vigorous growth. The nutritional properties of the feed (such as the protein and lipid content or, in greater detail, the amino acid, fatty acid, vitamin and mineral content) will depend on the knowledge of the fish requirements and the skill of the feed manufacturer to match this within a given set of economic and practical limitations. As such, the fish requirements and the dietary specifications may differ, sometimes quite markedly.

The nutritional requirements of a fish vary mainly depending on the species, its size/life stage and the environment. There can also be some requirements relating to the flesh quality of the product. For example, Atlantic salmon requires dietary pigments to make the flesh red. Conversely, for white-fleshed fish, such as striped catfish (*Pangasianodon hypophthalmus*), raw materials containing pigment, such as corn, should be avoided in the grow-out phases to reduce the risk of making the flesh an undesirable yellow colour.

Research has determined the optimal nutritional requirements for several species of fish, and this information is developing for many others. Such work tends to focus on achieving the maximum growth rate from a given set of nutrients, ensuring that the nutritionally optimized diet will provide vigorous, healthy growth under optimal conditions. However, such optimized diets are often expensive to produce commercially – depending on the cost of the constituent raw materials and the fish performance relative to the market price. Therefore, feed manufacturers (whether in a factory or on-farm) will have to make sacrifices in the dietary specifications or in raw material choice, which will reduce the nutritional capability of the feeds but should enhance the economic returns of the farmer. In practice, formulations – meaning raw material recipes – will be altered regularly by feed producers due to changes in the availability and price of the raw materials, in order to control cost while ensuring nutritional benefits, as observed by Rana, Siriwardena and Hasan (2009).

The initial dietary specifications arising out of the formulation used will have an important influence on the best achievable eFCR and growth rate when using this feed. There can also be an impact on flesh quality and filleting yield. If the feed does not have sufficient protein to meet the fish demands for growth while providing a large quantity of energy, the fish will tend to deposit an increased quantity of fat in its muscle and visceral cavity. Fat in the visceral cavity tends to be wasted, especially if the fish are gutted or filleted before marketing, and as such, the feed resource is wasted. The accumulation of muscle fat can reduce the quality of the flesh as perceived by the buyers and, as fish often deposit fat in the belly walls, fillet trim specifications generally demand that these are removed and discarded.

Feed formulation to meet fish nutritional requirements is a difficult science, balanced by economics. Simple fixed feed formulations may be effective but are unlikely to be optimized for fish performance, especially given the variation in raw material quality (see Section 4.2). Feed manufacturers with no knowledge of fish requirements or raw material quality, and driven only by economic concerns, will not be able to formulate effective feeds, thus unknowingly sacrificing nutritional quality to secure a steady unit price of the feed.

4.2 Raw material type and quality

Having determined the dietary specifications to be used, the feed formulator will then choose the mix of raw materials and their qualities. A large range of raw materials is available globally; large feed companies may be able to source globally, while smaller companies may have to focus on local purchases or buy through traders. Obviously, different raw materials have different nutritional properties, but even within one raw material type there can be much batch to batch and seasonal variation, resulting in different qualities that will affect the precise nutritional value.

At the most basic level, the proximate composition of the raw material may vary – for example, protein content in wheat and lupin varies between cultivars and country of cultivation (Glencross, Curnow and Hawkins, 2003), as well as the nutrient and energy digestibility of the resulting feed including the different cultivars (Glencross *et al.*, 2008). This can be measured relatively easily by a supplier or feed company using near-infrared (NIR) analyses or Kjeldahl analysis for total nitrogen (which is then mathematically converted to total protein using a conversion factor). However, it is well known by nutritionists that not all of the protein in a given raw material can be digested and absorbed by the fish.

A range of digestibility studies have been carried out on different raw materials for some species of fish (e.g. McMeniman, 1998; Eusebio, Coloso and Mamauag, 2004; Glencross, 2006; Williams, 2007), and the digestibility of the protein

must be taken into account during formulation, unless the diet contains a large proportion of surplus protein. Even within one raw material type, processing can affect protein digestibility. Fishmeal gives a good example of this. Over-drying of fishmeal reduces the digestibility of the protein dramatically (Higgs *et al.*, 1995). Similarly, processing of plant proteins from the raw state into concentrates can also impact digestibility (Glencross *et al.*, 2004). Knowledgeable feed manufacturers will therefore work closely with their raw material suppliers to ensure that the processing conditions are optimized to retain protein digestibility.

Raw materials can also be affected by contaminants. Plant raw materials are prone to the growth of moulds that may produce mycotoxins. Knowledge of the impact of these on fish is developing, but impacts are well known and respected elsewhere – in pig and poultry production in particular. A major challenge with these contaminants is the high degree of variation that can occur within just a small part of one batch, where the mould may grow and create high concentrations of the toxins that may not be present in the rest of the batch and so may be undetected.

Raw materials can also be deliberately adulterated by suppliers and traders. Cheap or low-quality products may be mixed with the raw material to bulk them out or increase their apparent protein content, thus increasing their apparent value and the profits of the seller. A recent well-documented example was the mixing of melamine with various raw materials. Melamine has high nitrogen content, so when blended with a poor-quality raw material and analyzed for protein content by the Kjeldahl method, the apparent protein content is good, but the product will have low nutritional value. Unfortunately, melamine has toxic effects on humans; its appearance in the food chain resulted in many illnesses, and even some fatalities when the product was mixed with milk to increase the apparent protein content (WHO, 2008). It is still being found in raw materials, as are other cheap, high-nitrogen compounds such as urea, which cost time and money to screen.

Poor or variable raw material quality is a significant problem for the feed industry, where commercial volumes are so large that it is not feasible to check every batch in great detail; similarly, it is impossible for small-scale farmers to perform such checks. Cheap raw materials may be cheap for a reason, but also variations may be unknown to the feed supplier and only appear once the fish have eaten the feed. It is the responsibility of the feed manufacturer to check the raw material suppliers and work with them to ensure that the ingredients that they supply have the properties expected of them.

4.3 Technical properties of the feed

Having determined the composition of the feed, it is also the job of the feed manufacturer to make it of a technical quality that allows that feed to be consumed by the fish. Factors to take into account for this are:

- form of diet (unprocessed materials, mash, mince, formed pellets or extruded pellets);
- impact of cooking;
- density;
- hardness;
- moisture content;
- pellet size; and
- dust and fines.

The form of the diet will determine not just whether the feed is easily consumed by the fish, but also whether it can be stored and the methods available for feeding it to the fish. Figure 3 shows images of the some of the variety of feed types used in different farm situations.

FIGURE 3
Examples of different feed types used in aquaculture

Notes: Top left: low-value shellfish fed whole; top right: frozen low-value fish blocks left to float in a cage; middle left: fish trimmings fed chopped into a cage; middle right: cage-side mince preparation; bottom left: on-farm wet-pellet mill; bottom right: extruded salmon pellets

COURTESY OF DAVE H.F. ROBB.

4.3.1 Trash fish/low-value fish and wastes

Low-value fish (so-called 'trash fish'), trimmings of fish from processors, dead fish, and animal and plant wastes may be fed directly to fish. This practice is often used in developing aquaculture countries (Edwards and Allan, 2004), and there are concerns related to the variation in quality of the different sources in terms of their nutritional value (Edwards, Tuan and Allan, 2004), as well as the potential to spread disease (Kim *et al.*, 2007).

In order to help the fish eat the material, it may be chopped up before feeding, which takes some considerable time. Each piece may then have considerably different nutrient content, so fish eating this feed will vary greatly in nutritional intake. Farmers

often recognize the nutritional limitations of these feeds and may use additives, either injected into the fish pieces or sprayed on top prior to feeding.

4.3.2 Mashes

Mashes are frequently used by farmers in developing countries who often prepare their own feeds, as commercially produced diets may not be available or are thought to be too expensive. Raw materials can be mixed together according to some recipe or recommendation and given to the fish. However, there is a great concern that the mash will disperse and leach nutrients quickly, reducing the benefits to the fish and potentially fouling the waters through enrichment.

4.3.3 Minces

Minces are again prepared on-farm. Generally low-value fish, or fish or meat trimming wastes, are minced up with plant raw materials as a binder in an attempt to create a nutritional or economic balance. The mix tends to be based on previous experience and the price of raw materials, perhaps with some guidance towards a recipe that would provide appropriate nutrition. The resulting paste, which can be quite coarse, is then either fed directly to the fish or formed into 'spaghetti-like pellets' by pressing through a die and cutting. These pellets may then be dried in the sun on-farm before being fed. Sun-drying makes the pellets hold their form a bit longer in the water, which increases the chance of fish eating them before they dissolve. Also the texture of the mince may reduce the losses by leaching as compared to the mashes. However, sun-drying will also encourage oxidation of oils and the ultra-violet light will also lead to degradation of vitamins (especially vitamin C) at the surface, reducing the nutritional properties of the mince.

4.3.4 Pellets

In contrast to mashes and minces, pellets (both steam pressed and extruded) that have been properly dried will tend to stay whole in water for an extended period, allowing more to be eaten by the fish. They can also be stored for a period of time at the place of manufacture or on-farm, whichever is more convenient. This increases flexibility for farmers. Such pellets are also dry, so provide more nutrients for the same weight as mashes and minces. This increases their weight for weight efficiency and reduces the need for farmers to carry large volumes of wet feed to the fish.

If the raw materials are mixed together efficiently before pelleting, each pellet should have roughly the same composition, so each fish fed pellets should receive similar nutrition. If the formulation is correct, this will be close to the optimal required for the fish. Mashes and the use of waste or by-product materials in particular cannot achieve this.

4.3.5 Cooking or extrusion

Cooking the raw materials has an important effect on the carbohydrates. The cooking process breaks down long-chain carbohydrates, making them more readily digestible by animals. Shorter chain sugars and starch can therefore be used to some degree for energy, rather than being excreted or even causing enteritis in some species. Such cooking is achieved in steam pellet mills to some extent, but properly used extruders achieve more efficient cooking through both direct heating from the steam and from the mechanical forces imparted in the extrusion process. This is a more advanced (and expensive) technique in feed preparation that will not be available for farm-made feed manufacture, increasing the benefits from the resources used by commercial feed mills.

4.3.6 Density

Feed density, and therefore buoyancy, is an important tool for feed control on-farm that can be manipulated during the manufacturing process. Some species prefer to feed from trays or the bottom of the pond; as such they require fast sinking feed. Other

species prefer to eat in mid-water, staying away from the surface, but are unwilling to eat feed once it hits the bottom; thus they require slow- to medium-fast sinking feeds. However, with sinking feeds it is difficult to monitor whether all of the feed is being eaten or whether it is just dissolving into the water, particularly if the water is not clear. Therefore, for species that do not need to eat from the bottom or in mid-water, floating feed can be an excellent option, allowing farmers to see whether the fish are eating or if feed is being wasted.

Feed density is most easily manipulated in extruded feeds, where the degree of cooking and expansion of the starches in the raw materials will determine the capacity of the feed to float or sink. Farmers should be able to request their feed manufacturer to provide feed suitable to the requirements of their system (floating, slow or fast sinking). In contrast, due to their relatively high density, farm-made feeds (minces and wet pellets) will tend to sink, irrespective of the requirements of the fish or the farmers.

4.3.7 Hardness

Cooking and drying the pellets causes them to harden. This gives greater pellet integrity, meaning that they will stay as whole pellets longer in the water. Pellets are tested by feed manufacturers to ensure that they remain whole for at least a specified time, which is particularly important for slow-eating species, such as sturgeons, shrimp and abalone. The drying also allows the pellets to be stored after manufacturing for a longer time, which increases flexibility for farmers; however, excessive drying can reduce the nutritional value of the feed and make it less digestible to the fish. Additives promoting binding can also be used, particularly for steam pelletizing or for feeds which should remain whole for a long time in the water before they are eaten – such as shrimp feed. Properly extruded feeds should not require a binder, providing sufficient starch quantity and quality is provided in the formulation.

4.3.8 Moisture content

Very wet feeds have to be fed to fish almost immediately, but dry feeds (in practice about 10–12 percent moisture) can be stored for several months under the proper conditions. Care must be taken by the feed manufacturer to control the maximum amount of moisture in feeds that may be stored, or moulds may develop during the storage period.

Feeds with high moisture content also are much heavier per unit of nutrients offered. In practical terms, this means that farmers have to move a much greater weight and volume of feed when using wet feeds in order to provide the same nutrient input to the fish. This can result in a high cost of logistics, depending on the location of the farm.

4.3.9 Pellet size

Fish are generally relatively opportunistic when it comes to the size of their food, taking both large and small particles. However, particularly for small fish, there is a maximum size that can be eaten in one mouthful. Large fish can eat many small particles, but nutrition will be more efficient if they eat one larger particle, having to expend less energy to collect this. Feed manufacturers therefore recommend pellet sizes for different fish sizes, depending on the species. The maximum size of pellet offered will depend on the manufacturing process and the technical properties required of the feed; a larger pellet will be harder to dry and is more likely to break if fed by machine.

It is important for feed manufacturers to aim to produce uniform pellet sizes, as this helps to provide a uniform nutritional dose per pellet and is also an indicator of good control of the pelleting process. If there is a lot of variation in pellet size within a batch of extruded pellets, this can indicate problems with the extrusion process that may have impacts on the nutritional and other technical properties of the feed. Feed companies should monitor pellet size after cooling to check that the products are within the specifications provided to the customers.

4.3.10 Dust and fines

Very small particles, termed dust and fines, which float on the water and eventually dissolve or disperse, will tend not to be eaten by larger fish. This is not only a waste of feed, but can potentially enrich the water, resulting in unwanted algal growth and poor water quality.

Feed manufacturing companies normally have specifications (limits) on the quantity of dust and fines acceptable in a batch of feed. The problem arises during feed manufacturing when the movement of the pellets can cause them to break into small particles. Sieves and screens should remove the majority of these, but some will be carried through to the final product. Further breakage can occur during transport of the feed to the farms and during the feeding itself, as discussed below. However, regular checks on the quantity and feedback to the feed manufacturer should keep this under control.

Once the feed has been prepared, it perhaps has its greatest potential to promote healthy growth of fish. Now it has to be delivered to the fish; from this point on, generally what can happen to it will reduce its potential. For feeds made or mixed on the farm itself, transport to the fish is relatively straightforward. However, feeds made off the farm, including factory-made feeds, are generally produced some distance from the farms and so some kind of bagging (unless bulk transported) and transport is required.

5. LOGISTICS OF GETTING FEED TO FARM

The logistics of getting the feed to the farm have an obvious impact on the finances of the farm – distance and method of transport in particular. Lorry (truck) transport is more expensive than boat, being less fuel efficient, but can be more flexible for small deliveries and of course for delivering to inland facilities.

Bulk transportation of feed offers a potential to reduce costs. Traditionally, feed has mainly been sold in small bags (10 to 40 kg) that can be carried easily around the farm. However, the cost of packaging is significant over a large volume of feed. Transporting the feed loose in a lorry, or even better in a boat, removes this cost, but then requires on-site storage of loose feed, typically in some kind of silo. An intermediate step towards this has been the use of 500 kg or 1 tonne bulk bags, which reduce the packaging costs without the need for large silos at the farm site. However, both of these solutions to reducing packaging require short-term investment in feeding equipment – which opens up further opportunities for cost savings in the long term, but which may be prohibitive to small-scale farmers or businesses in financial difficulties.

Aquaculture is carried out in a variety of situations, many of which are not close to the industrial areas where commercial feed is generally produced. Some countries do not yet have commercial feed production of the quality demanded by the farms and so have to import feed, necessitating a long journey. During such journeys, which can last over a month in some cases, it is essential that there is consideration of the severe environmental conditions that may occur.

Constant high temperatures can cause oil to leak out of medium- to high-fat diets, reducing their nutritional qualities. Oxidation of the oil can also occur, causing problems and resulting in rancidity that may be repellent to the fish. Fluctuations in temperature during transport can cause accumulation of moisture, which could encourage the growth of moulds and soften the feed.

Feeds should be kept dry at all times. Transporting feed by boat can create a risk of moisture entering the feed if it is not properly protected. Open boats are often used for feed transport to farms (especially in small waterways), where the feed is exposed to spray and rain. In such cases, a secure cover should be in place over the feed to keep it dry, so helping to reduce the chance of mould growing during later on-farm storage.

It is essential to plan the logistics of feed movements from the factory to the farm site in order to protect the feed as much as possible. Some damage may be unavoidable with current systems, in which case investments should be planned for the future to provide extra protection.

6. ON-FARM ACTIONS

6.1 Storage

Feed can be stored on-farm or nearby for some period of time before it is fed to the fish. Normally a farmer would try to minimize the storage time, as this is ties up working capital. However, typically part of a feed batch will be stored for at least a week before being fed. During this time, if it is not properly stored, the feed can get wet and become soft and mouldy. It can also be stolen from the farm or attacked by pests and vermin, causing a loss of feed volume and also perhaps spreading disease. Too often the quality of storage facilities available on-farm do not protect against these issues (Figure 4).

FIGURE 4
Examples of feed storage on-farm

COURTESY OF DAVE H.F. ROBB.

Notes: Top left: feed left outside, directly on the ground, with animals around; top right: feed in a roofed and walled store, but still on the ground; centre bottom: feed in a roofed, walled store, off the ground and wrapped in plastic.

Feed storage facilities on-farm must be secure from theft and pests. Often, pest control measures can be implemented in the storage area, such as the use of safe traps or baits that are clearly marked and kept separated from the feed. Keeping feed store doors closed when the store is not being used is a simple way to promote security.

Feed store design is important to keep the feed quality. The goal is to create a dry atmosphere that does not get too hot. A high roof with secure walls and aeration will help to achieve this. The floor should be sealed and raised above the ground outside to stop water from entering. Even so, bagged feed must be stored on clean pallets to ensure that if water does enter, it will not touch the feed. The pallets will also allow air to circulate under the feed bags.

Where possible, the feed store should be arranged to facilitate the operation of a so-called 'first in – first out' system. This means that the feed in the store that was delivered first should be used first, which will assist with stock control, making sure feed is used within the specified date. Arrangement of such a system will also assist with the development of a traceability system, which is becoming more often required by commercial customers globally for food safety purposes. Batch numbers of the supplied feed, which should be provided by the feed manufacturer, can then be traced through the fish grown, providing confidence in the safety of the production chain to the end consumer.

A well-managed feed store will be clean, tidy and dry. This layout will help the site manager to see clearly how much feed and which types are in stock, allowing planning of the next purchases well in advance, rather than in a panic at the last minute.

6.2 On-farm top-dressing

It is common practice to add various chemicals to feed on-farm for a variety of reasons, the most common being to add medication in order to treat sick fish. Another reason is to use additives not previously included by the feed manufacturer. This so-called 'top-dressing' has been seen as a necessary part of many farm operations, but it also raises some important issues. Typically, a solution containing the chemicals to be added will be sprayed onto the feed, mixed in and allowed to dry or absorb before being fed to the fish. Carried out efficiently, this can be a successful way of getting the chemicals to the fish, but there are concerns.

The first issue arises over the source of the chemicals. Poor control over the quality of chemicals used, especially for medications, is partly responsible for the development of pathogen resistance to various antibiotics and other drugs used in aquaculture. Unscrupulous traders will dilute drugs and replace them in the packages with no warning as to the new dose. Inappropriate storage for long periods of time, either at the trader or on-farm, can also lead to a reduction in the active compound. Both lead to inadequate doses being administered, resulting in no health benefit to the fish and possibly in the development of resistance to the drugs by the disease agent. While many countries raising fish, and most importing countries, have regulations concerning the chemicals that can be fed to fish entering the food chain, many small-scale farmers are not aware of these details. Regulations concerning the withdrawal period for drugs prior to slaughter (the time taken for a chemical concentration in a fish to decrease to an acceptably safe level after it was last fed) are also often in place, but again the farmers must be aware of these in order to comply. Failure to observe these regulations has direct human safety implications, as well as long-term market image impacts for countries exporting their fish.

A second issue arises over the ability of the farm to create a homogeneous dispersion of the chemicals over the feed. Larger units may be able to use a specialized coating machine to spray a controlled dose onto the feed, while others may use a large mixer with a spray to try to obtain homogeneity. However, often very large volumes of feed need to be treated, and this will require time and facilities, leading to short cuts being taken. Smaller farms may not be able to get access to such equipment and instead will spray on the chemical solution by hand over a pile of feed, which they may mix later. This leads to a very heterogeneous mix across the pellets, which will result in some fish getting a high dose of the treatment, some an inadequate dose and some getting none at all.

A worker health and safety issue can arise with on-farm top dressing feeds. Some of the chemicals added can have severe human health consequences if exposure is not controlled, an obvious example being the addition of hormones or antibiotics to feed. Workers may receive little or no training about the risks and proper handling methods and often will have little safety equipment available for use.

The final area of concern over top dressing arises from the solvent used to disperse the chemicals when they are added to the feed. There must be sufficient knowledge of the chemicals to ensure that the right solvent is used – lipid or aqueous based – or the correct dispersion will not be achieved. Furthermore, the solvent should be able to carry the chemicals into the feed before it is given to the fish. There is a very real concern that a large portion of the top-dressed chemicals will disperse in the water before the fish have a chance to eat the feed, which may have environmental impacts outside the farm following water discharge, as well as obviously reducing the dose eaten. In order to reduce this loss, farmers may leave the feed to dry in the sun before feeding the fish, but for some additives or therapeutants (such as vitamin C), the sunlight will just destroy their properties, thus rendering the treatment useless.

It is tempting, perhaps, to suggest moving top-dressing to the responsibility of feed companies; certainly they could obtain the necessary equipment to homogenously coat feed with the required chemicals. Feed companies are in a position to help improve the use of additives and in-feed medication, but are often reluctant to be involved for very good reasons. The application of various chemicals to the feed in the factory runs a high risk of carryover from one feed batch to the next. This risk is unacceptable to a commercial company and requires dedicated production lines. Also, many farmers do not want to have to order medicated feeds or special additives through the feed company, as they prefer to make their own proprietary mixes. In some countries, addition of medicines such as antibiotics by the feed companies is actually prohibited by law.

The need to top-dress with nutrients will be reduced when the feed nutritional profile matches the requirements of the fish better. This will come from better knowledge of the needs of the fish and the feed companies matching this with their products. However, there still could be the need to add health treatments to the feed. Given the risk of poor on-farm top-dressing practices, it is important that a series of best practices are recognized. It is also important that farmers are given proper advice on which chemicals to use (from both the legal and efficacy standpoints).

If top-dressing is to be applied after the feed has been manufactured, it is important to use legally approved and appropriate chemicals. Farmers should be supplied with a regularly updated list of such chemicals – or at least the ones that are specifically banned. This could be provided by local authorities, co-ordinated centrally in each country.

It is also important that simple equipment is available to try to spread the treatments homogenously onto the feed. For large volumes, a drum spray coater is by far the best, where the flow rate of feed and chemicals being sprayed onto it are controlled by the operator. However, this is obviously too high an investment for many small units. Simple units can be made with a belt moving the feed beneath spray nozzles. Correct calibration of the dose may be difficult, as it could be hard to regulate the liquid spray rate and the belt speed, but there should be greater homogeneity of the dose in the feed. Such units could be shared between farmers, but of course there is the risk of chemical carry over from one treatment to the next.

Training on the use of top-dressing, including discussions on whether it is really needed, should be led by local support units, NGOs and local authorities. Such organisations can also perhaps provide efficacious equipment for top dressing, so that when it is required, it can be used appropriately.

7. FEEDING THE FISH

It has been shown above how the quality of the feed that is made depends not just on the formulation and processing, but also on the way in which it is transported and stored on-farm, well before it is even put in the water. Once the farmer decides to feed the fish though, it is far from certain that the best use of what quality is left will be made.

7.1 Feeding method

The first issue that arises is how to get the feed into the water. There are many solutions in use, depending on the feed type, pond or cage size, density of fish and, of course, investment required (Figure 5).

FIGURE 5
Examples of feeding methods on-farm

COURTESY OF DAVE H.F. ROBB.

Notes: Top left: tipping feed from a platform into the water, with no dispersal; top right: casting the feed by hand from a platform; middle left: casting the feed by hand from a boat in a pond; middle right: a fixed feed spreader over a cage, using a spinning disc to flick the feed out; bottom left: a small blower system on a boat next to a cage; bottom right: feeding activity over the area where the feed is falling from the blower previously illustrated.

Unlike most other farmed animals, fish are generally not presented with a pile of feed that can be topped up when the farmer notices that it is low. The aquatic environment

generally does not allow this, washing away the feed and leaching the nutrients into the water. Due to this, fish are generally fed distinct meals, although for some kinds of fish some farmers try to leave feed out to be consumed over a longer period.

The simplest solution is just to hand feed, throwing the feed into the water from one place. If there is a lot of feed, farmers may just tip the bags into the water, using floating pellets to disperse slightly. Alternatively, they may use a scoop to flick feed out across the water, covering some 4 or 5 m range. This works best with dry feeds, as wet feeds are too heavy to do this for long. The problem with this method is that the feed enters the unit at only one point and often is given rather slowly. This means that not all the fish will get the opportunity to eat at every meal.

An alternative for wet feeds is to put the feed or mash into bags with large holes in them. These are then arranged in the water (normally this is done in ponds) where the fish can pull the feed out of the bags. This has been adapted somewhat for species such as sturgeon, where sinking pellets are spread on a flat net like tray that is suspended in the water. As these fish are relatively slow eaters that prefer to take food from the bottom, they can swim over the tray and take the pellets at their own rate. With such a system, it is essential that the farmer has a dialogue with the feed company in order to ensure that the feed will be capable of remaining whole for long enough in the feeding tray to be eaten by the fish. If the integrity of the pellets is not sufficient, they will dissolve before they are eaten and their nutrients will be wasted.

Various demand feeders have been investigated by farmers. Fish will hit a target (normally a lever in the water) that causes a release of feed in the immediate area. This is an attempt to allow the population of fish to eat more or less continuously as they require – perhaps also at times that are not convenient for the farmers to feed, such as at night. It is also an attempt to allow the smaller fish to eat, as the bigger, dominant fish cannot defend the food source all the time. However, in reality, there are often not enough of the feeders in each unit to allow all fish to eat optimally.

Instead, farmers with larger units have started to spread the feed further across the units, either by using small boats to move around the unit or by using a machine to cast the feed out. Using boats to move around large units allows a degree of dispersion, but often farmers still just tip the feed into the water from the boat, creating a line of feed. The use of machines to spread the feed really starts to allow better feeding practices, dispersing the feed so that all fish have a chance to eat and also providing a large volume of feed quickly so that the larger fish cannot defend the feed easily.

Simple machines use spinning discs to flick the feed out from a hopper, spreading the feed several metres from the source and rapidly moving a large quantity into the pond over a large area. However, an improvement to this method uses air to blow the feed out, covering a much larger surface area of the unit while still providing a large quantity of feed in a short time. Again, it is important for farmers to work closely with feed companies when using such machines. The machines impart a lot of force onto the pellets, and if the pellets are not strong enough or the machines are incorrectly set up, the pellets will break, creating dust that can block the machines or float uneaten on the water surface. Pellet strength can be increased to some degree, but creating too strong a pellet is expensive and also makes it more difficult for the fish to digest. So it is also important to check the setup of the machine to ensure that there is a smooth flow of pellets through it, with no sharp bends or poor joints that will smash the fast-moving pellets.

The cost of the machines means that, at least initially, farmers will often have only one machine to feed several units, moving between each during the day. This forces the feeding regime into distinct meals, where the rate of feeding and quantity of feed to give in each meal is important. In a large unit, dispersing the feed effectively is essential in order to allow all fish to have a chance to get the food they require. However, it also brings its own problems in terms of controlling the amount of feed given, which will be addressed later.

7.2 When to feed (or when not to feed)?

Incorrect decisions on whether or not to feed will lead to poor feed utilization. If feed is given when not required, it will be wasted. However, if feed is not given when it is required, the fish will use their body reserves for energy and so will not gain weight – and may even lose weight if starved for too long. Both result in an increase in eFCR for the population of fish in the unit.

The timing of feeding each day should be determined by the nature of the fish; some fish will only eat diurnally or should eat when the oxygen content in the water is high. However, farmers generally feed at their own convenience rather than seeking to work with the biology of the cultured stock. This can change with the use of automated machines, which allow remote feeding in a controlled manner.

The most information on daily timing requirements is probably available for Atlantic salmon. These fish have a high requirement for oxygen, and when they are digesting food this requirement increases (Forsberg 1997; Cook, McNiven and Sutterlin, 2000). They should therefore be fed so that they can digest their feed when the oxygen concentrations are highest in the units, i.e. during the day, when any plankton in the water will be adding oxygen. As the oxygen demand peaks a few hours after feeding, late evening feeding should be avoided; also the oxygen content in the water decreases after dark as the plankton stop producing oxygen.

The environmental conditions in the unit will have a large impact on the requirements of the fish for feed. The water quality governs this, with its complex interactions between temperature, oxygen, nitrates, nitrites, ammonia, pH and carbon dioxide, to name but a few. However, little information is available on how environmental factors impact the feed requirements of fish. The interactions are often so complicated that simple experiments have not been able to explain the limits, or take into account all factors simultaneously. Farm data are not often collected well enough to allow large-scale datasets to be analyzed. This is an area that needs to be investigated more thoroughly in order to develop better practices for feed management, perhaps concentrating on temperature and oxygen at first, but later including other factors.

For Atlantic salmon, their high oxygen demand results in seasonal periods when feeding should be restricted or stopped. Under some conditions, dissolved oxygen concentrations will naturally decrease (mainly with higher temperatures) to levels where the fish could suffer from oxygen depletion if they are fed. Appetite decreases, so the fish tend to eat less. Initially, the low oxygen will also result in poor feed digestion, but can even cause mortalities in extreme situations. As a result, farmers should monitor the oxygen content of the water daily and reduce or avoid feeding when the conditions indicate that a risk is present. The situation will be similar with other fish species, but guidelines for the critical limits of oxygen are not yet determined, or perhaps even noticed for species such as striped catfish that are popularly thought to be tolerant to very low oxygen concentrations.

Some farming situations allow water quality interventions, such as changing or treating the water and adding oxygen, to be implemented. These have often been implemented to allow the fish to survive, but need to be optimized so that the fish can thrive – better water quality will allow the fish to digest and assimilate their food more efficiently. Simple aeration systems, for example, will increase the available oxygen to assist more efficient feed utilization (e.g. Cole and Boyd, 1986). Although the optimal water quality for growth is unknown for many fish species, sensible assumptions can be made, even for very robust species such as striped catfish that are able to survive in water of very poor quality.

Fish health status should also impact the decision on whether to feed or not. Healthy fish obviously will require feed, unless the environmental conditions preclude it. However, stressed or diseased fish have different requirements. Little is known of the relationship between the wide range of diseases affecting farmed fish species and their feed/nutrition requirements. In the farming of Atlantic salmon, treatment of

some diseases, such as salmon pancreas disease virus (SPDV) – an alpha-virus that can cause high mortality – has traditionally required that the fish be starved, as the stress of feed on the digestive system is too great. However, working with feed manufacturers to supply a more digestible feed has resulted in the fish being able to digest feed and so more effectively combat the disease than if they were existing on their own body reserves. This has been an important step in the treatment of diseases, as chemicals are often given to the fish through the feed (as discussed earlier), so if some fish are not feeding, the treatment will not be effective over the whole population.

7.3 Feeding rate: how much, how fast and how often?

When feeding a large population of fish, it is important to ensure that all fish can eat optimally. If this is not achieved, some fish will eat more and grow faster than others, which will enable them to become dominant; this makes the situation worse as the dominant fish defend the feed supply, bullying smaller fish away from it. As a result, there will be a wide range in fish sizes at harvest, which may not meet the targeted requirements of the customers.

The first factor to control is the amount of feed to be given to the unit. This is determined principally by the biomass of fish in the unit, with the individual fish size being the next most important consideration. Where seasonal variations in temperature and photoperiod are significant, exact feed requirements will fluctuate accordingly (however, in tropical regions, seasonal variations in photoperiod are unlikely to be significant). Seasonal adjustments are still being researched for the main aquaculture species. However, in general, feed intake, as well as digestion and subsequent growth, will increase with increasing temperature until the temperature rises to the point at which maximum consumption is reached (e.g. Andrews and Stickney, 1972; Glencross and Felsing, 2006; Usmani and Jafri, 2002). Above this temperature, feed intake will start to decrease as the fish become temperature stressed.

In order to determine the biomass in the unit, it is essential that the farmer conducts sample weighings on the fish and performs adequate record keeping. At input, there should be an accurate measure of the number and total weight of fish stocked into the unit. After this initial calculation, the farmer should make regular assessments of the growth of the fish and estimate the current total biomass, taking into account the estimated loss in biomass through mortalities and escapes. This estimate of current biomass should be used to guide how much feed should be given to the fish, with visual cues being used to give fine control.

Smaller fish tend to eat a greater percentage of their body weight per day as compared to larger fish. This fact is recognized in most species, and feed companies often make suggestions as to the amount of feed to be given per day as a percentage of the fish weight. The size of the fish in the unit will not always be exactly known, but can usually be predicted from regular sampling and growth estimates, which will be described in more detail later.

In general, there will be a relationship between the amount of feed eaten by the fish relative to its requirement for feed (so-called ‘appetite’) and both the growth rate and eFCR. Growth will increase with increasing feed consumed until a maximum growth rate is achieved. Feeding beyond this will actually slightly decrease the growth. Conversely, the eFCR will decrease at first with increased feeding until a break point is reached; beyond that, the eFCR increases again. What is interesting is that the maximum growth rate is achieved at a higher feeding rate than the minimum eFCR – as the growth is not so efficient at higher rates. If the fish are under-fed, on average they will not grow as fast as is possible for their conditions. As the amount of food increases, they will grow faster, until achieving their maximum possible growth rate. Some fish species will stop eating around this point in time, but others may continue to gorge on food, unable to override their opportunistic feeding instincts.

Seriously under-fed fish will tend to have a high eFCR, as they will use the feed they eat just for energy – respiration, swimming and hunting for more food. As the amount of food eaten increases, they will start to deposit muscle and other tissues, gaining weight and reducing their eFCR. At a point still before the maximum growth rate is reached, the minimum eFCR is reached (the point of this will depend on the species and the feed characteristics). Beyond this, the eFCR increases slowly with extra feed given until the maximum growth rate is reached. After this point, the eFCR will increase more rapidly, as extra feeding cannot result in extra growth and therefore is just wasted. This model gives the farmers a conundrum as to whether to feed for maximum growth or minimum eFCR – two different economic targets that depend on the price of credit (fast growth target) and on whether the fish price is low (eFCR target).

As has been previously discussed, spreading the feed is part of the solution; however, the speed of feeding is also important. Generally, at the start of a feeding session the fish will feed very aggressively. Fish will then begin to calm as individuals become satiated and move away, leaving the others to continue feeding. Work with salmon has shown that at the start of the feeding, a large number of pellets should be available in order to reduce competition between the fish. With time, as individuals become satiated, the rate of pellets entering the water can be reduced, but individual fish will still be feeding actively at this time. Interestingly, the fish also move from feeding at the surface to feeding at depth, which is less stressful to them, as they are away from the light and human activity. This creates a problem when visual cues are used to assess satiation: if surface activity alone is used to indicate feeding, then many fish will be underfed in a meal. This is addressed in more detail in the sections that follow.

The number of meals per day is also of importance to the farmer in order to optimize feed management. As previously discussed, small fish require a proportionally larger amount of food per day than large fish. In order to achieve this, smaller fish have to receive many smaller meals over the day, while larger fish have a large enough alimentary canal to ingest their whole daily requirement in one meal.

Feed companies often provide information on the minimum number of meals required per day according to fish size. These recommendations tend to be a balance between what can be eaten by the fish and the convenience of the farmer. In theory, it is likely that a larger number of small meals per day fed to the unit in a way that ensures that all fish can eat at the same time will be closest to the ideal. This would be the closest to providing a constant supply of feed that fish can access when hungry. In practice, this is not possible due to constraints on being able to spread feed over the whole unit regularly in a way that does not waste feed.

8. MONITORING FISH AND FEEDING

In order to optimize the use of the feed, the farmer must observe what is happening and how the fish are responding. This sounds obvious, but is often not done in a structured way.

8.1 Feeding observations

The goal of feeding observations is to ensure that the fish have eaten to satiation at each meal. How this is done will change according to the fish species and the clarity of the water. The simplest way is to use floating feed and to ensure that all of the feed given is eaten, then adding a bit more to see if the fish will still eat more (i.e. if they been underfed initially). This is a very good option for surface-feeding fish and in murky water. However, some species will not feed on the surface, and often farmers will only check to see that all feed is eaten, not that the fish are satiated, so underfeeding will occur.

Farmers may also look for fish activity to indicate feeding. Again, for surface feeders this can be a good indicator, although it is likely that as the number of fish actively feeding decreases towards the end of a meal, the subdominant fish will still be feeding. As an example, Atlantic salmon will feed voraciously at the surface as the meal

begins, but as the dominant fish become satiated, the subdominant fish will continue to feed lower in the water column as the feed sinks. If the farmer is only using surface activity as the cue to stop feeding, the subdominant fish will not receive enough feed and consequently will not grow as well.

To assist with this problem, underwater cameras are often used in sites where the water clarity is sufficient. The use of cameras opens up the visual control of the farmer, allowing most of the unit to be monitored, thus hopefully ensuring that all fish have fed before the meal is stopped. In large cages, this is essential in order to achieve optimal control. Cameras allow large farming units to be operated remotely from a control centre. Farmers can watch the fish from a central place, feeding regularly by machine as the fish require it. Feedback is immediate, and so the feeding should be efficient if carried out by trained and dedicated personnel. However, underwater visibility can be reduced by silt or algal blooms, limiting the efficacy of this system.

An alternative to the use of cameras to monitor feeding activity is the use of Doppler controlled systems. A sensor is placed strategically in a cage and feed presented. If the sensor detects no pellets passing it, feed continues to be given. As the sensor starts to detect pellets, the feeding rate may be reduced or the feeding system switched off. After a period of time more feed will be given and the process repeated. This system can work well providing the sensor is in the right place and there are no strong currents through the cage to sweep uneaten pellets away before being detected. It can also operate effectively in turbid waters, as it does not rely on visual information. However, it cannot replace the versatility of cameras, which also provide information on health-related behaviour and, as such, cameras should preferably be used if feasible.

As noted above, the use of cameras is not possible in murky waters and so different strategies have to be used. Shrimp farmers will often place small trays in different parts of the unit. They spread the feed over the whole unit and routinely check the trays to ensure all feed is eaten. This works well in ponds, and daily checking of the trays will ensure that there is little accumulation of excess feed. However, it will not work for fish kept in cages or for feeds that are not highly water stable, as such feeds will dissolve before the trays can be checked. LiftUp® systems for cages can work in a similar fashion, with both pellets and mortalities brought to the surface collectors, using airlift systems to draw up water and waste from the bottom of the cage to a surface collector where it can be assessed by the farmer.

With no visual cues, farmers have to rely on calculated fish feed requirements, i.e. tables. Most fish feed manufacturers have circulated general feeding recommendations or suggestions covering how much to feed (normally as percent fish body weight per day) for different fish size ranges, and such information is often printed on the feed bag. Few feed company-produced tables are adapted for environmental conditions such as the current photoperiod or water temperature, often because the feed company does not have the knowledge for this. Even with relatively accurate tables, there will be variations in demand for feed (e.g. due to fish health status).

Given the absence of visual feedback when using tables to feed the fish, either because the water is murky or because the farmer is relying solely on the tables and not on visual observations of the fish themselves, it is essential to monitor growth to determine how well the feed is being used. This requires regular sampling and comparison of the average weights with a predicted (or standard) growth curve, both of which are discussed below.

8.2 Fish sampling

Fish sampling is an essential part of any responsible aquaculture practice; if farmers do not know what is in the units, they cannot be farming the fish according to their needs. It has to be carried out in a structured way in order to provide a useful input to the farmer. As such it will give an estimate of the average weight of fish in the unit as well as an indication of the variation in weight.

Obviously, when sampling a unit, it is not practical or necessary for farmers to weigh every individual fish in the unit. There needs to be an informed choice as to how many fish to sample, which will depend on the accuracy demanded by the farmer relative to the size of the fish. If a normal distribution in weight is expected in the unit (a reasonable assumption for standard fish growth), then Table 1 can be used as a guide to determine the number of fish to sample, depending on the average fish size expected.

TABLE 1

Recommended minimum numbers of fish to be sampled to estimate the mean live weight with 95 percent confidence[1]

Acceptable accuracy (± g)	Estimated fish mean live weight (g)							
	50	100	200	500	1 000	1 500	2 500	5 000
5	10	20	70	X	X	X	X	X
10	10	10	30	X	X	X	X	X
25	X	X	10	30	120	X	X	X
50	X	X	X	10	30	70	180	X
100	X	X	X	X	10	20	50	200
200	X	X	X	X	X	X	20	50

Note: [1] For example, if the mean weight is estimated at 1 000 g and an accuracy of ±50 g is considered acceptable, then a minimum sample of 30 fish should be taken

Source: Crampton and Sveidqvist (2003).

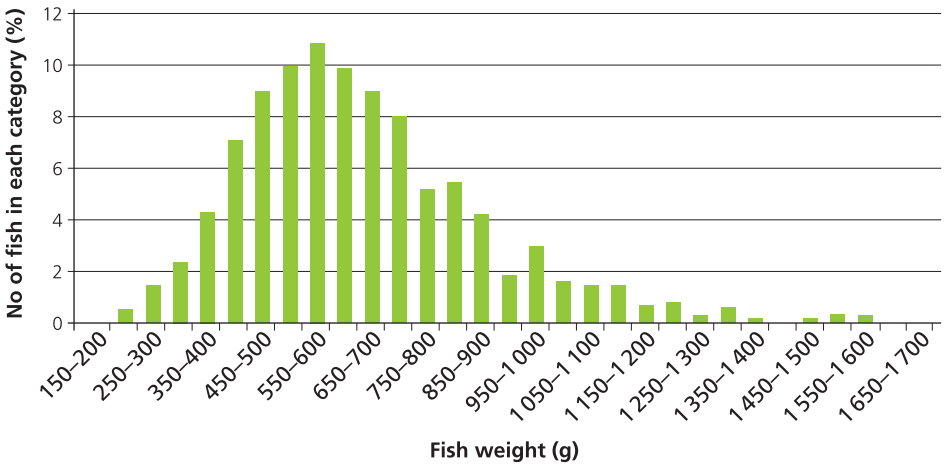
Two options are open to the farmer when weighing samples. The first is to find a mean weight (the minimum requirement) and the second is to estimate the variation in weight within the unit (much more informative).

If the mean weight is all that is required, the fish can be bulk weighed and counted (there is no advantage to weighing individual fish). Still, as can be seen from Table 1, the more fish that are weighed, the more closely the estimation will approach the actual population mean.

If information on the variation in weight is required, then individual fish will need to be weighed, still with the numbers sampled determined by Table 1. Once the required number of fish are weighed, not only can the mean weight be determined,

FIGURE 6

Example of the distribution of fish weights within a sample, taken from an Atlantic salmon farm



Source: Crampton and Sveidqvist (2003).

but the distribution of weights can be plotted and the farmer can quickly see how the population lies (Figure 6). This will give important information on how well the fish are being fed across the population, as discussed below.

The sampling frequency is determined by the degree of accuracy required by the farmer, balanced by the practicality of sampling. A population should be sampled at least once a month; the cost of sampling in terms of staff time is far outweighed by the cost of under or over-feeding the fish.

8.3 Using sample data

Once the sample data have been gathered, it is important to use them efficiently. Some feed companies will assist farmers to interpret their data, but many will not. For some species, the background data are not always readily available, and thus farmers may have to make a comparison based on their own experiences.

The first aspect is to plot the mean weight of the fish from the previous samplings of the population against an expected growth curve for that species. An expected growth curve can be derived from an average performance curve for that species, from industry data or from the previous data obtained by the farmer. For fish species that have a fixed breeding season (i.e. species that only breed at a certain time of year, so that the juvenile input time to the farm is quite fixed), the growth curve will most likely be similar for all inputs, with allowance for annual fluctuations in water temperature. However, for fish that breed continuously, the growth curves to harvest will vary with the season, depending on when the fish were spawned. To interpret growth curves for such species, it is important to have the relevant data available or a good theoretical model that can integrate the seasonal input effects. When analyzing growth curves, it is also important to know the size of the fish at input. Bigger fish put on weight faster, so, for example, if two adjacent, identical units are stocked at the same time but one is stocked with bigger fish, the growth curves will not be parallel.

The second aspect is to assess the variation of fish weights in the sample. If the fish are growing well, it is natural that there will be some variation, and this variation will follow a normal distribution. However, under-feeding a population will cause a skew in this curve. Relatively minor under-feeding may show a distribution having a long tail of small fish – fish that are subdominant and thus not able to compete as successfully for feed. If removed from the unit and fed to satiation, these fish will grow just as well as the others. More serious under-feeding or poor feed distribution may result in a distribution with a longer tail of large fish – dominant fish that can out-compete the rest of the fish for the feed that is being given. This can only be corrected if the small and large fish can be separated by grading and splitting into different units, where they can be appropriately fed. This operation carries a risk of stressing the fish, reducing the growth rate and potentially resulting in a clinical disease, as well as causing extra work. It can only be done effectively if there are enough units available.

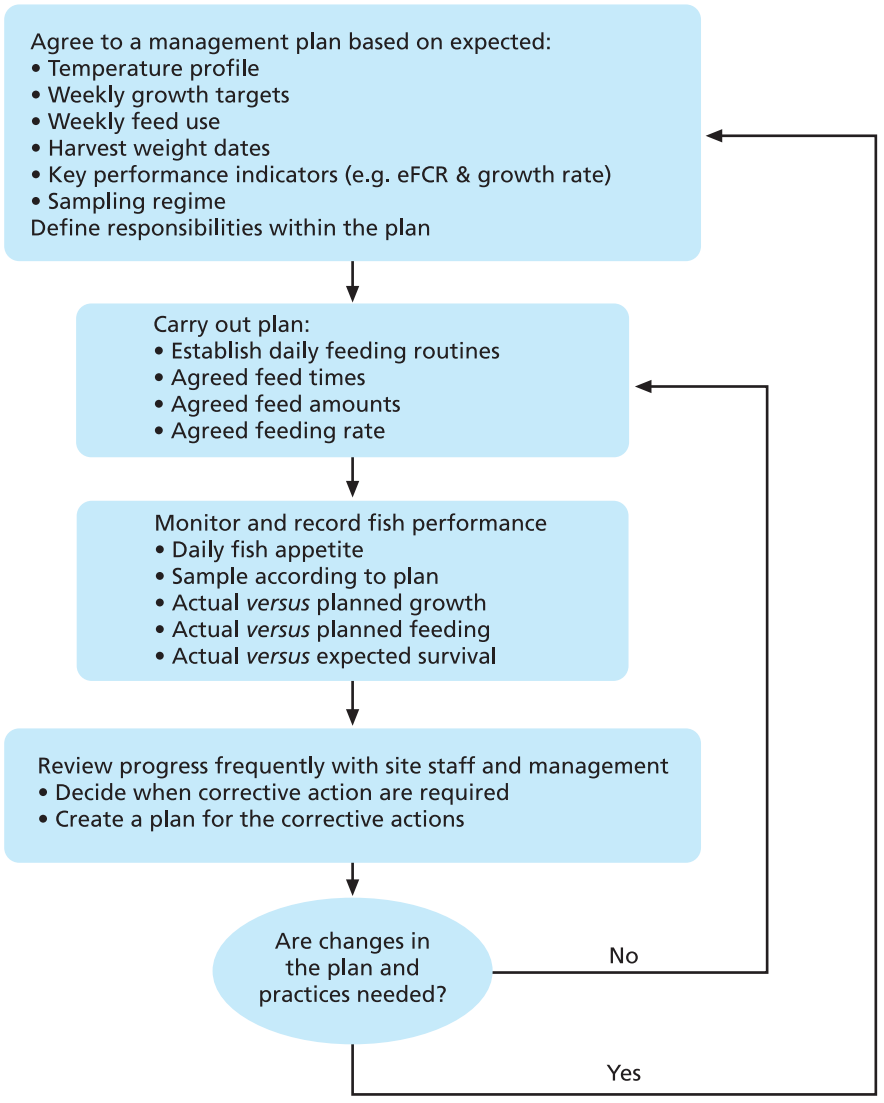
The degree of size variation is important to the farmer, not just to judge if the fish are being fed correctly but also to meet the market demands at harvest. There is generally an optimal harvest size for the farmed fish, and if there is a large weight variation in the population, relatively few fish will be at that target size. Often both small and large fish are penalized in the market place, giving the farmer a clear incentive to control the size variation as much as possible by good feeding practices, with grading as a secondary measure.

9. PLANNING AND MANAGEMENT

Large farms carry a very high value of fish during each cycle, and feed is a large part of the input costs, as was mentioned previously. Therefore, it is important that responsible farmers plan their production cycle in detail, so that if there are deviations they can try to correct them quickly. Proper planning will also help farmers to predict when their stock will be ready for harvest, in many cases giving them negotiating power to secure

better contracts from their customers. Figure 7 presents a simple schematic diagram for the creation, use and revision of such a plan. Although in many cases such planning is very simple, it is frequently not carried out. Farmers who decide to create a plan and manage their farms accordingly find many extra benefits in terms of control over their business, as opposed to using completely unplanned feeding regimes.

FIGURE 7
Aspects for the creation, use and revision of a feeding and feed management plan for growing fish



Source: This review.

9.1 Growth curves

Expected growth curves need to be developed for the farm that are relevant to the species cultured, the feed type, season and farming conditions. As has been noted, seasonal temperature fluctuations will advance or retard the growth rates of species that have year-round breeding. Localized seasonal events such as wet/dry season changes and flooding may also have relatively predictable impacts on fish growth. Different culture conditions (e.g. intensive, semi-intensive or extensive; pond or cage or tank) will also have impacts on the growth rates. Farmers should know what they are able to expect.

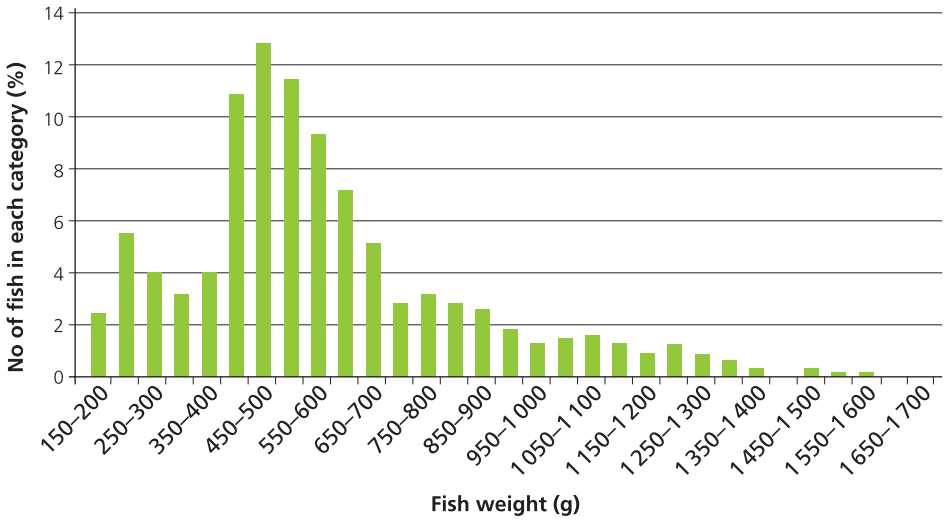
Given the complexity of the interactions, often the most representative data for a farmer will come from his own records. A regular review and interpretation of past growth data will allow farmers to develop their own growth curves. Feed companies can also be in a position to work with farmers to help them develop this and benchmark against average performance across a range of customers, which provides a stronger tool. Such practical growth models can be used to show average or maximum growth rates against which the current growth rate is benchmarked.

Farm data is notoriously 'noisy' and often contains many errors that, unless rigorously removed, will have a large leverage on the model. Therefore, theoretical models based on fish energetics and some feed trials can also be employed. While such models are useful as a benchmarking option, farmers tend to dislike them because they are not based on 'real' farming conditions; however, they can show what the fish is capable of if placed in good conditions. Such models can be developed from strategically designed trials that cover the main drivers of the species-relevant factors most likely to affect growth on the farms.

9.2 Weight distribution

As has been discussed above, the distribution of individual fish weights will also give farmers important information on their feeding practices. The degree of underfeeding can be assessed by the deviation of the weight distributions from a normal distribution (Figure 8). Corrective action to provide the correct amount of feed or to distribute the feed more effectively so that all fish can eat will help reduce the unusual weight distribution. Regular sampling of the fish will help the farmer to keep on top of this issue.

FIGURE 8
Example of a skewed distribution of Atlantic salmon weights arising from under-feeding



Notes: A few fish have been able to get more feed and have thus grown much more rapidly; a small group has barely grown from lack of feed, starting to develop a bimodal distribution.
Source: Crampton and Sveidqvist (personal communication, 2013).

9.3 eFCR

Regular sampling will also allow farmers to calculate their eFCR up to that point in time. With a good estimation of the total population weight and knowledge of the total feed put into the unit, an estimation of eFCR can be made. However, a good deal of care must be taken when interpreting this value mid-cycle, as the true population weight will not be known. Most importantly, the exact number of fish in the unit will

not be known at this stage, since mortalities and escapes are likely only to be estimated (if included at all). An estimated eFCR mid-cycle could be useful, but the actual one may be much higher if the mortalities or escapes are high. By the end of the production cycle, the estimated eFCR may be very different from the actual one.

9.4 Corrective actions

Having made a plan and anticipated a growth rate, it is important that the farmer can interpret the data and take corrective actions. This can often be done with the feed company, which should have good experience in interpreting growth curves, even if the corrective action is not its responsibility. The exact reactions will be specific to the conditions and should, to a certain extent, be anticipated. Such actions could include:

- confirming sufficient feed distribution;
- confirming sufficient feed delivery speed;
- checking the nutritional and physical quality of the feed;
- re-sampling fish to check the data;
- re-counting fish in the unit (mortalities or escapes may be important);
- performing a health check on the fish (disease may be slowing growth and increasing FCR); and
- checking for predators (predators will stress the fish and cause them to stop eating, as well as taking fish themselves).

This is not an exhaustive list; however, it is clear that while the farmer will coordinate these actions, many different parts of the supply chain can be involved, from feed to health companies. This demonstrates that effective farming and feed management can only come from a combined effort from within the supply chain.

9.5 Training and support

Given the value of the feed input, few farmers pay enough attention to the issue of training and supporting their staff in feed management. Many farm staff will receive in situ training from current employees and will have little opportunity to learn from external experiences. This can encourage bad practices and prevent development. As such, it is common that many farmers are unaware of the potential a fish species has for growth and feed efficiencies, so have little ambition to improve.

Practical feed management training courses are required for many species. These need to focus on the benefits of feed management and how to do it, giving farmers insight into the potential of the fish they are raising. While cost is always cited as a limiting factor, farming companies can recoup the costs of such training very quickly if the courses are useful. The real challenge is to find reputable trainers who know about feed management and can provide practical training in regions close to the farmers.

Support is also an important issue, so that farmers will benefit from assistance in interpreting their feeding performance and can discuss with someone else how best to improve. The support provider should have the benefit of a range of experiences in feed management, so that he or she can compare the results of the farmer and suggest options to proceed.

10. THE ROLE AND RESPONSIBILITY OF THE FEED MANUFACTURER

Having discussed the importance of feed and feed management in aquaculture, the role and responsibilities of the feed manufacture should also be mentioned. For some companies, their vision of the role of the feed manufacturer is just to sell feed profitably. Very often, the business model for such companies stops at the point of sale. Other feed companies – generally larger businesses – have their own nutritionists who are able to develop the feeds to improve the quality or price of the feed. They may also employ technical staff to support the sales people and the customers beyond the point of sale.

It is very clear that the feed companies have to be profitable in order to survive and grow. Some would suggest then that they should just focus on making cheap feed. However,

it is interesting to note that in Viet Nam this strategy has failed for many aquaculture feed mills hoping to ride on the back of the growth of the striped catfish production. Of 60 mills registered in 2008, over 30 are now idle or have even never been used. Such a strategy cannot support a large number of companies and consolidation will occur into a few large, efficient businesses. However, farmers will also differentiate in time according to the efficiency of the feed – determining if the feed is fit for the purpose it is sold.

Focussing solely on making feed cheaply does little for emerging aquaculture industries, where a lot of development work is required. In developed industries, where a lot is already known about the nutritional requirements of the fish, this may work, but in fact practical experience is that the customers still demand more from the feed companies.

In developing aquaculture industries, feed companies should have a responsibility to develop the feeds. This may take time and resources, but is an important aspect to support their customers. Often little is known about the requirements of the fish species in the practical conditions of the farms. Feed companies are in a good position to help collate this information from many farmers and to try to develop feeds and feed strategies that will promote healthier fish growth. This may be through nutritional development of the feeds, using internal nutritionists or consultants. It could also be through data recording and interpretation with farmers, to understand the risk areas better.

Whilst many feed companies cannot afford their own nutritional team to develop feeds beyond what can be learnt openly, they should be able to support their customers beyond the point of sale. Technical teams regularly visiting farmers and suggesting opportunities for improvement are not expensive and if they are used correctly will build a strong bond between the feed company and their customers. Training of such technical staff can be co-ordinated with local authorities or recognised experts – care must be taken with the selection as some information may not be up to date or correct.

In summary, it is clearly the role of the feed company to be profitable through the sale of feed that is fit for purpose. However, in the opinion of the authors, it is also the responsibility of the feed company to develop the products that it sells to support the growth of its target industry. We also believe that after-sales support towards for customers is important, providing that this is carefully developed. This can range from follow-up of the performance of the fish growth using the feed, to much broader technical advice on a wide range of aquaculture matters – in other words the feed supplier becomes a general source of information. Not all feed companies will be able to provide the after sales support. This will be a point of differentiation within the market and the customers will decide, through their purchasing patterns, which strategy is sustainable in the long term.

11. CONCLUSIONS

Feed is a major input into aquaculture, both in terms of quantity and value. Managing feed and getting the greatest performance out of it is a skilled job that requires optimizing interactions between the farmer, the feed company and the fish. Many companies do not pay enough attention to this aspect of control, viewing feeding the fish as unskilled manual labour. It is also important to realize that getting the best results out of the feed is a joint effort between the different parts of the supply chain, coordinated by the farmer.

In order to get the best fish performance, in terms of growth or feed efficiency, from a certain weight of feed, it is essential to have control over key factors. These are:

- feed fit for purpose;
- feed delivered securely to the farm;
- feed stored on the farm in a manner that will maintain quality;
- healthy fish;
- an optimum environment;
- accurate knowledge of the number of fish in each unit and their size; and
- knowledge of feed requirements.

Feed planning must be carried out against an anticipated growth curve for the fish, and farmers should monitor fish performance against this plan, taking corrective actions as necessary.

For a great part of the global aquaculture industry, maintaining control over all factors happens rarely, if at all. There is a clear requirement for improved communication and feedback between farmers and the feed companies, in order to match delivered feeds to needs. There is also a need for the farmers to invest in ways to improve on-farm feed storage and use, as well as to improve fish husbandry conditions so that nutritious feeds will be fed to healthy fish.

It is, perhaps, a very utopian vision to think that aquaculture can achieve and maintain full control over all factors. However, with good planning and ambition (awareness of what can be achieved), it is possible to steer production towards that goal.

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Feed management and on-farm feeding practices of temperate fish with special reference to salmonids

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ABSTRACT

Under all aquaculture conditions, feeding practices have economic, environmental and social implications. Even with nutritionally adequate and balanced 'environmentally friendly' feeds, inappropriate feeding practices can lead to significant feed losses causing adverse effects on water quality and decreasing the sustainability of aquatic animal production. Much progress has been made in the production of salmonids through improving nutritional value, feed physical characteristics, and feeding practices in order to optimize feed and nutrient utilization and to reduce potential environmental impacts. There is strong scientific evidence that proper feeding systems and strategies should give due consideration to the behavioural rhythms of the species cultured and the nutritional quality of the diets. There are currently a number of quite sophisticated feed distribution systems for use in salmonid production, their utility depending upon how well they are adapted to the species and size of fish and to the culture site. There are also a number of devices to monitor the feeding activities of salmonids. Modern feeders and feeding schedules have been developed by feed manufacturers based on fish size, water temperature and the energy content of feed, and appropriate directions have been provided to achieve maximum growth and feed utilization under diverse environmental and culture conditions. Most of the progress made with salmonids can be adapted and applied to other temperate marine finfish, as well as to tropical species totally relying on man-made feeds. This includes feed processing technologies as well as on-farm feed management practices and strategies. Accumulating evidence shows that other marine finfish grown in cages as well as tropical fish reared in ponds, can adapt themselves to modern demand feeders. Such devices also hold much promise for understanding the specific feeding rhythms of new species and for obtaining quantitative data on the control of voluntary feed intake as affected by dietary nutrients. Knowledge gained and achievements made in the development of nutritionally wholesome starter feeds, continuous feeding by the use of belt-feeders for rearing larval or juvenile fish, application of bioenergetic principles to develop feeding tables and the use of extruded feeds can and should be applied to tropical aquaculture species.

1. INTRODUCTION

Under aquaculture conditions, feeding practices have economic, environmental and even social implications. Even with nutritionally adequate and balanced 'environmentally friendly' feeds, bad feeding practices can lead to significant feed losses that cause adverse effects on water quality and decrease the sustainability of aquatic animal production. In the present review, the objective is to show the progress made in feed management practices in salmonid aquaculture, taking into account the evolution of the nutritional value and physical characteristics of feeds; recent advances in feeding methods and practices employed to optimize feed and nutrient utilization; and strategies for waste management that are designed to reduce environmental impacts. Since most of the feeding practices and strategies are based on conceptual ideas on the control of feed intake in fish supported by experimental work, some information on such concepts is also provided. It is also becoming clear that most of the progress made with salmonids, with regard to the feed processing technologies and on-farm feed management practices and strategies, can be applied to other temperate marine finfish, as well as to warmwater species totally relying on man-made feeds.

2. PRODUCTION OF SALMONIDS

Over the past three decades, the growth of salmonid production around the world has been high, increasing from about 75 000 tonnes in 1970 to more than 2.4 million tonnes in 2010 (Table 1). This growth is undoubtedly due to the progress made in the areas of fish nutritional science, feed processing technologies, feed development and feed management practices. This increase in production also provides us with abundant information, not only with regard to the physical and nutritional characteristics of feeds but also regarding the management of feeds at the farm level. This review focuses mainly on rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*), the two major species of salmonids that together make the major contribution to global salmonid production.

TABLE 1

Production of salmonid species over the past four decades (tonnes)

Species	1970	1980	1990	2000	2010
Atlantic salmon (*Salmo salar*)	294	5 288	225 642	895 808	1 425 968
Rainbow trout (*Oncorhynchus mykiss*)	64 741	145 124	277 815	491 927	728 448
Coho salmon (*O. kisutch*)	250	2 560	39 164	108 626	137 510
Sea trout (*Salmo trutta trutta*)	1 470	2 270	4 888	6 937	24 017
Chinook salmon (*O. tshawytscha*)	0	0	14 998	16 664	13 541
Arctic char (*Salvenilus alpinus alpinus*)	0	0	69	1 093	3 156
Ayu sweetfish (*Plecoglossus altivelis altivelis*)	3 197	7 898	13 017	9 324	6 484
Trouts nei[1]	759	3 352	11 202	12 632	17 949
Whitefishes nei[1]	4 400	5 800	1 562	2 233	4 284
Others	0	0	802	1 751	49 780
TOTAL	**75 111**	**172 292**	**589 149**	**1 546 995**	**2 411 137**

Note: [1]nei = not elsewhere included.

Source: FAO (2012).

3. EVOLUTION OF NUTRITIONAL PROFILES OF FEEDS

Since the farming of salmonids is totally dependent on formulated feeds, these are formulated to supply all the essential nutrients and energy in tune with the needs of the animal for the maintenance of vital physiological functions, such as growth, reproduction and health. An additional imperative in aquaculture, especially with regard

to salmonids, is that of ensuring both environmental quality and the nutritional value of the fish produced, both of which are related to the nutritional quality of the feeds used.

Because the nutrient requirements for all the species under aquaculture are not known and are difficult to determine, it is common practice to extend data from more or less closely related species. This is very much the case with regard to salmonids as a group. Based on studies undertaken with juvenile rainbow trout grown in freshwater, relatively complete knowledge has been gained on the quantitative needs of rainbow trout with regard to all the essential nutrients (Cho and Cowey, 1991; Hardy, 2002). In contrast, despite the high level of production of Atlantic salmon at a global level, the nutrient requirements of this species are not so well defined as for rainbow trout. The limited information available is based on studies undertaken with small fish grown in freshwater, before the parr-smolt transformation, after which they are grown in the sea. In the absence of specific data on their nutrient requirements, information gathered from other salmonids, such as rainbow trout and Pacific salmons is extended and applied to develop feeds for Atlantic salmon (NRC, 1993; Storebakken, 2002).

Early feeds for salmonids were rich in protein and low in energy content. One major change that has occurred over the past 30 years is the shift from feeds with relatively high protein content (>50 percent) and low total lipid level (12 percent) to feeds that are lower in protein content and higher in lipid levels (Hardy, 2002; Storebakken, 2002). Much attention has been paid to developing high-nutrient and energy-dense feeds (Cho *et al.,* 1991; Bureau, Kaushik and Cho, 2002). Current feeds have high digestible energy levels thanks to the use of extrusion technology that allows the inclusion of high levels of oil. At the same time, instead of reasoning in terms of crude protein levels, close attention is now given to the digestible protein levels.

In recent years, one major concern has been the relatively high dependence of salmonid feeds on fishmeal and fish oil, which are finite sources whose use raises questions regarding their future availability and cost. Thus during the past decade much effort has been directed towards replacing the high levels of fishmeal and fish oil in the feeds for Atlantic salmon and rainbow trout. Based on data provided by Tacon, Hasan and Metian (2011), we can see that although the feeds for salmonids (salmons and trouts) represent 9 percent of the aquafeeds used globally, the production of salmonids necessitates the use of over 19 percent of all of the fishmeal and nearly 51 percent of all of the fish oil used by aquaculture (Table 2).

TABLE 2

Projected use of feeds, fishmeal and fish oil for the production of salmonids in 2010

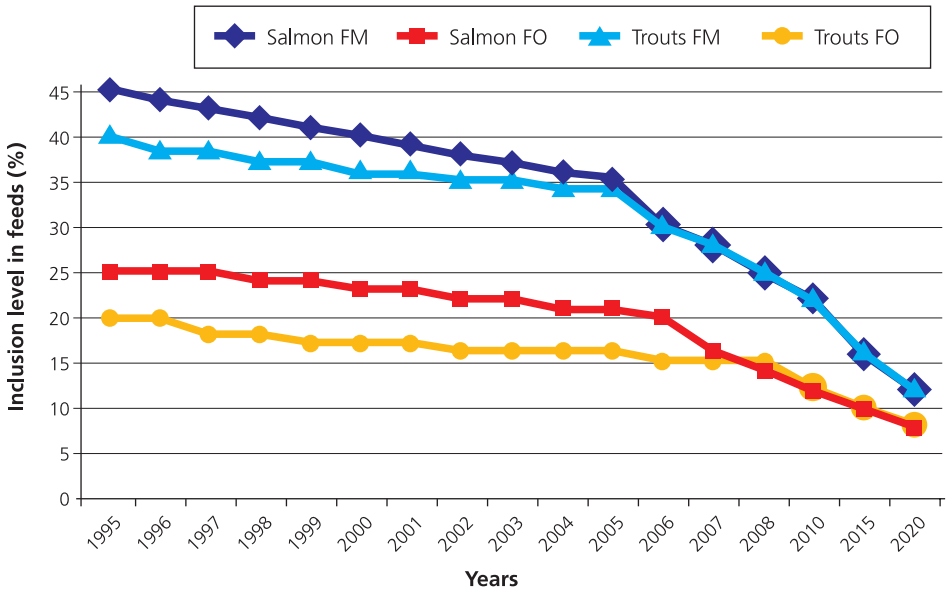
	Production (tonnes)	Feeds used (tonnes)	Fishmeal used (tonnes)	Fish oil used (tonnes)
Salmons	1 734 000	2 225 000	496 000	271 000
Trouts	746 000	970 000	213 000	116 000
Total salmonids	2 480 000	3 195 000	709 000	387 000
Total all fed species	21 201 000	35 371 000	3 670 000	764 000
Salmonids, % of total	11.7	9.0	19.3	50.7

Source: Tacon, Hasan and Metian (2011).

Over recent decades, significant efforts have been made by the salmonid industry to reduce the levels of inclusion of fishmeal and fish oil (Figure 1). Watanabe *et al.* (1998) demonstrated that rainbow trout could be grown over long periods with properly balanced non-fishmeal diets, even without any supplementary indispensable amino acid (IAA) Similarly, Kaushik *et al.* (1995) found that total replacement of fishmeal with alcohol-water extracted soy protein concentrate adequately supplemented with methionine led to similar growth and nitrogen utilization, compared to fish fed a fishmeal-based feed. Mambrini *et al.* (1999) showed that soy protein concentrate could

replace 50 percent of fishmeal in high-fat extruded diets for rainbow trout. Similar success has not been reported in other salmonids, such as the Atlantic salmon or the Pacific salmons, for high levels of substitution of fishmeal, even by protein-rich soybean products (Kaushik, 2008). However, with mixtures of plant protein sources that are properly selected and adequately supplemented with amino acids and in the absence of antinutritional factors, there is much potential for replacing high levels of fishmeal in the diets of most fish (Kaushik and Hemre, 2008) including rainbow trout, Atlantic salmon (Espe, Lemme and El-Mowafi, 2006) and other marine finfish such as European seabass (*Dicentrarchus labrax*) (Kaushik *et al.*, 2004) and gilthead seabream (*Sparus aurata*) (de Francesco *et al.*, 2004; Sitja-Bodadilla *et al.*, 2005). A major difference between Europe and other countries in this particular area is that terrestrial animal by-products (processed non-ruminant animal proteins) are not utilized by feed companies and farmers, whereas in other parts of the world their use does not raise any serious concern.

FIGURE 1
Changes in the inclusion of fishmeal (FM) and fish oil (FO) in the feeds for salmonids over recent decades and predicted further reductions



Source: Adapted from Tacon, Hasan and Metian (2011).

Given that high energy feeds for salmonids are rich in total lipid levels and that this has mainly been supplied through fish oil, there has also been significant interest in substituting the fish oil with other lipid sources. Much progress has been made in this regard in both Atlantic salmon and rainbow trout, and studies have clearly shown that in feeds containing some of fishmeal, additional fish oil can totally be replaced by single vegetable oils (i.e. rapeseed, soybean, linseed) or a mixture of vegetable oils. The changes in flesh fatty acid profiles that are bound to occur can be re-tailored, to meet human nutritional needs or demands, by a period of finishing with fish oil-rich feeds (Bell *et al.*, 2004; Richard *et al.*, 2006).[1] More recently, combined reduction in both fishmeal and fish oil levels in feeds for Atlantic salmon (Tortensen *et al.*, 2008), rainbow trout (Panserat *et al.*, 2009) and gilthead seabream (Benedito-Palos *et al.*, 2007) has been demonstrated through concerted efforts between various research groups.[2]

[1] Also see: www.rafoa.stir.ac.uk
[2] See, for example, www.aquamaxip.eu

The salmonid feed industry has thus undergone significant changes over the past 30 years by taking into account the progress in fish nutrition science, the technological advances in the feed manufacturing sector, the economics (by developing least-cost formulae) and the environmental consequences (by developing nutrient-dense, highly digestible, environmentally friendly feeds). In recent years, the industry has also been confronted with food safety issues and has taken adequate measures to reduce all potential feed-borne contaminants. This movement from least-cost towards least-risk is taken a step further by also considering all possible environmental burdens associated with such feeds (Papatryphon *et al.,* 2004).

4. EVOLUTION OF THE PHYSICAL QUALITY OF FEEDS FOR SALMONIDS

The global production of feed for salmonids in 2010 is estimated to range between 3.05 and 3.23 million tonnes (Tacon, Hasan and Metian, 2011; FAO, 2012). Feeds for rainbow trout and other salmonids have undergone major changes since the 1960s: from trash fish/terrestrial animal by-products through semi-moist feeds to dry pelleted feeds and to extruded high-nutrient and energy-dense feeds.

In the early days of salmon and trout farming, it was common to use trash fish as feed, with or without additional mixtures to supply other micronutrients and facilitate binding. It was also common to use moist feeds based on terrestrial animal by-products (bovine liver or spleen), along with trash fish or fish offal mixed with grains, milk products, bread, etc. The first nutritionally complete diets appeared about 1955 (Rumsey, 1994), which led to some of the pioneering works on the nutrition of salmonids. From a practical point of view, by the 1970s, the first ever dry feeds were formulated and developed for growing salmon (Pacific and Atlantic) and trout (EIFAC, 1971; Fowler and Burrows, 1971; Fowler, Banks and Elliott, 1972; Luquet, 1972). Semi-moist feeds, such as the 'Oregon moist pellet', were also being used initially and comparisons to dry pellets made to see the differences in efficacy of such moist pellets (Clark and Langmo, 1980). At some stage, feeds based on acid-preserved silage from fish offal were also promoted (Raa and Gildberg, 1982). Experimental studies have shown that it is possible to grow salmon over long periods with such semi-moist diets containing acid-preserved fish silage (Jackson, Kerr and Cowley, 1984; Dumas *et al.,* 1991). However, the economic viability of such practices remains to be demonstrated under practical farming conditions.

Another option is the production of a moist feed prepared from alkaline-preserved (pH 11.2) herring filleting by-products mixed with a crude binder based on seaweed. The mixture is then pelleted and immersed in an acidic bath to obtain the proper gelatinization characteristics. Studies undertaken with Atlantic salmon on the use of such moist feed appear to show promising results in terms of digestibility, growth and feed efficiency (Sorensen and Denstadli, 2008). Some studies have also attempted to make direct use of fish offal or trash fish by combining microwave and extrusion technologies, as a measure of waste recycling with the possibility of producing feeds containing up to 47 percent crude lipid (Hemre and Sandnes, 1999). The use of such moist pellets is also practiced in some cases, mostly for experimental purposes for evaluating the effects of different alternative sources (Hardy, Scott and Harrell, 1987; Waagbo *et al.,* 1994; Morkore and Austreng, 2004).

The adverse effects of moist and semi-moist feeds on feed stability and on environmental quality are generally recognized (Cowey and Cho, 1991), and all salmon and trout farmers now rely exclusively on nutritionally complete dry feeds right from first feeding throughout the production and reproductive cycles.

There are also differences between the feed processing techniques used in fish nutrition research and in practical feed trials. For the determination of nutrient requirements, for instance, purified ingredients are often blended with water, made into a 'spaghetti' and kept either frozen or dried and then crumbled before use.

Dry or steam pelleting is also used for experimental purposes. Dry pelleting, which is easily applicable in the animal feed industry, is done either with or without preconditioning, but cannot achieve lipid levels above 13 to 15 percent. Some double pelleting techniques can be used to reduce fines and increase pellet stability and lipid content. For almost two decades, extrusion technology, although more expensive and technically demanding than the conventional dry pelleting process, has been the major processing method for the production of salmonid feeds. Extrusion and, to a lesser extent, expansion techniques that are used for the manufacture of feeds for salmonids differ significantly in terms of heat as well as mechanical treatments (Table 3).

TABLE 3

Thermal treatments and duration of treatment for different feed processing methods

Process	Temperature (°C)	Duration (seconds)
Pelleting		
short conditioning	60–90	25–35
long conditioning	60–95	70–250
Expansion	80–140	5–15
Extrusion	80–200	30–150

Source: Melcion and van der Poel (1993).

From a nutritional point of view, extrusion and expansion processes are known to improve starch digestibility of cereals (Bergot and Brèque, 1983) and consequently lead to increased digestible energy levels. Even with pulses such as peas and lupins, extrusion can increase the digestibility of starch (Burel *et al.*, 2000). Extrusion is also known to decrease the levels of antinutritional factors and bacterial counts in the finished feeds (Melcion and van der Poel, 1993).

Extrusion technology offers flexibility in improving the use of cereals and can improve the physical characteristics of the finished feeds, with reduced levels of fines and greater water stability. A simple reduction in the amount of fines in the feed significantly improves suspended matter release in the aquatic environment while improving feed efficiency. However, depending on the raw material matrix, significant differences can be observed in terms of the physical characteristics of the feeds (Table 4).

TABLE 4

Some physical characteristics of pelleted and extruded fish feeds made with identical ingredient mixtures

Feed Mixture	A1		B2	
Feed Processing Technology	Pelleted	Extruded	Pelleted	Extruded
Mass/Volume (g/L)	612	580	633	504
Durability (Mechanical, Pfost) (%)	87	100	93	99
Durability (Pneumatic, Holmen) (%)	25	97	70	94
Floatability (% residues at 30 seconds)	0	0	0	10
Sinking rate (cm/second)	8	6.2	9.7	4
Water stability (% residues at 10 minutes & 1 hour)	30 / 89	0 / 4	17 / 37	11 / 92
Slope of particle breakdown (10–60 minutes)	0.0114	0.0097	0.0052	0.0167
Oil absorbing capacity (%)	16	18	16	31

Notes: [1] A: Basal diet containing fishmeal, fish oil, gelatinized starch, vitamin & mineral mixtures; [2] B: 80% A + 20% wheat gluten.

Source: Unpublished data of S.J. Kaushik and J.P. Melcion.

The advent and systematic use of extrusion and expansion techniques has made it possible to manufacture feeds with specific physical characteristics, such as increased stability and less fines, and to tailor buoyancy and nutritional profiles, such as the reduction of antinutrients and above all the possibility to increase the fat level in the feeds to increase digestible energy levels. Indeed, most extruded pellets are top-dressed or vacuum-coated with oils to achieve penetration of the oils into the feed and to reach final fat levels of 30 or even 40 percent. Certain heat-labile nutrients such as ascorbic acid and astaxanthin, feed attractants and other additives are also post-coated once the extrusion process is over. Water stability of feeds is not a major issue for salmonids, as both rainbow trout and Atlantic salmon generally consume feeds very quickly after delivery into the water without much loss of nutrients through leaching. However, in cases when lipid is not properly top-coated on the extruded feed pellets, a thin layer of oil may be observed on the water surface.

In both Atlantic salmon and trout, broodfish are grown in freshwater in land-based farms where they are fed broodstock feeds that are generally rich in long-chain polyunsaturated fatty acids supplied by fish oil and enriched in vitamins (C or E). In the initial stages, broodstock used to be fed moist-feeds comprising herring, sardines or smelt depending on local availability. Very soon, formulated dry feeds were developed and these are currently used in all cases.

Eggs are stripped from females and the milt collected from males is used to fertilize the eggs. Salmonid eggs, which are normally between 5 and 8 mm in diameter, have a long incubation period of about 400 to 500 degree days. At hatching, the free-swimming larvae weighing about 100 mg are fed complete feeds of small particle size (300 to 600 µm diameter). Starter feeds for first-feeding alevins and fry are made by crumbling extruded pellets. Other techniques, such as cold-extrusion using a spheronizer or marmurizer, render it possible to produce feeds with uniform spherical particles of small sizes suitable for first-feeding fry or fingerlings. Such feeds are generally rich in protein and low in total fat content.

5. FARMING PRACTICES

Rainbow trout are mainly grown in freshwater, although a small quantity is also produced in sea cages. In most land-based farms, rainbow trout are grown in raceways, generally of concrete construction and with a continuous supply of freshwater from a river system or natural underground spring, and the effluent water is released back into the river after sedimentation of suspended solids. Depending on the source of water supply, water temperature in these farms will either follow the natural seasonal changes in river temperature or be constant, in the case of water drawn from natural springs. Water flow rate and several physicochemical characteristics can vary depending on season.

After hatching, both rainbow trout and Atlantic salmon are grown in tanks or basins supplied with freshwater. For Atlantic salmon, prior to transfer to the sea, specific feeds containing salt, betaine, nucleotides and other supplements are used in order to improve the osmotic balance of fish undergoing smoltification. In the marine environment, salmon are reared in cages, the dimensions of which vary considerably, and depend solely on formulated feeds. Depending on the size and stage of the life cycle, the feed utilized varies in particle size and nutrient profile (Table 5).

TABLE 5

Pellet particle size used for different sizes of Atlantic salmon and rainbow trout, with crude chemical composition of the feeds

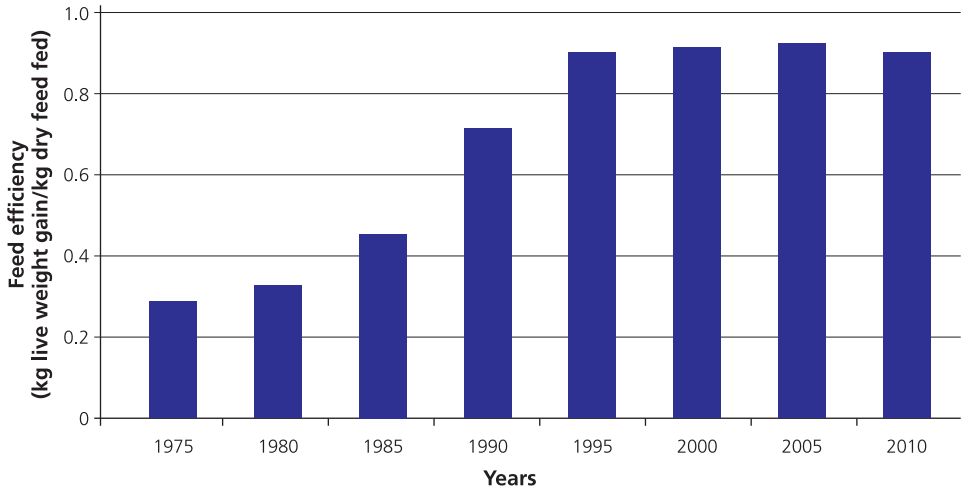
Fish body weight BW (g)	Particle diameter (mm)	Crude protein (%)	Crude lipid (%)	Digestible energy (kJ/g)
<0.3	0.3	50–55	18	18–19
0.3–0.8	0.5	50	18	18–19
0.8–1.5	0.8	50	20	19–20
1.5–5	1–1.2	50	20	19–20
5–10	1.5–1.8	50	20	19–20
10–30	2	45–50	22	19–20
30–100	3	48–50	24–26	19–20
100–250	4	46–48	26–28	19–20
250–500	5	44–46	28–30	20–21
500–1 000	6	44–46	28–30	20–21
1 000–2 000	7–7.5	42	30–32	21–22
2 000–3 000	9	40	30–32	21–22
>3 000	11	40	30–32	21–22

Source: Compiled data from commercial feed companies.

The improved physical and nutritional characteristics of extruded feeds have led to significant beneficial effects in terms of fish growth and feed efficiency in salmonids (Figure 2).

FIGURE 2

Improvement in feed efficiency in Atlantic salmon production 1975–2010



Source: Myrseth (2005) and unpublished data of S.J. Kaushik.

5.1 Feed choice, availability, transportation and storage

All salmonid farmers use commercial feeds purchased from dedicated feed manufacturers. Three major feed manufacturers supply almost 80 percent of the feeds for salmonids. Some salmon farming companies have their own feed manufacturing facilities as part of vertical integration. Currently, no farmers resort to on-farm feed production, but in a few cases farmers can make small amounts of speciality feeds (e.g. medicated feeds) using various kinds of mixers to mix such additives with the commercial feeds they purchase.

Feeds are manufactured by commercial companies and are continuously made available throughout the year. Depending on demand, feed is delivered by trucks for farms on land or by dedicated boats to the cage-farm sites. There are even special feed delivery vessels such as 'silos to silos' supplying feeds directly from the factories to the cage farms. Feeds are delivered in small bags of 25 or 60 kg, in large bags of 500 kg or 1 tonne or in bulk, depending on the volume of purchase and the type of feed. On reception at the farm sites, feeds are stored in dedicated ventilated storage rooms or in large silos (Figure 3) where they are stored for long periods.

Feed labelling is also an important issue. Currently in Europe most, if not all, salmon and trout feeds are described in sufficient detail through labels giving both ingredient and major nutrient composition. Such labels or the accompanying documents also clearly provide information on the conditions and duration of storage.

FIGURE 3
Feed silos at a land-based freshwater rainbow trout farm

COURTESY OF FAO/S.J. KAUSHIK.

5.2 Feeding methods

In parallel with advances in formulating adequate feeds and in processing technologies for producing feeds of diverse nature that meet the demands of fish, efforts have also been directed towards the improvement of on-farm feed management practices. Research towards understanding the underlying physiological mechanisms involved in the control of voluntary feed intake and feeding rhythms or patterns, as affected by environmental factors including nutrition, have provided valuable information (Houlihan, Boujard and Jobling, 2001) on this topic. As with all poikilothermic animals, feeding schedules for rainbow trout and salmons vary with water temperature. Voluntary feed intake also varies with the body mass of fish, small fish consuming more per unit body mass than larger fish.

5.2.1 Feed distribution by hand

On land-based farms such as raceways, rainbow trout are most often fed by hand (Figure 4). Hand-feeding is also practiced for rearing broodfish, using semi-floating pellets in order to closely monitor feed intake. Hand-feeding is also practiced in the rearing of Atlantic salmon in small farms. Hand-feeding requires a clear idea of how

FIGURE 4
Hand-feeding is commonly practiced in the rearing of rainbow trout in raceways

COURTESY OF G. CHOUBERT, INRA.

much feed is to be distributed to a given tank or cage. This is generally done by using feeding tables provided by the feed manufacturers themselves (Table 6) or by the farmers developing their own feeding tables based on past experience and observation. One recognized advantage of such hand-feeding is the capacity of the farmer visually to observe the feeding behaviour of the fish stock and adjust the quantity of feed to be distributed accordingly.

TABLE 6
An example of a feeding table for Atlantic salmon (% BW/day)

Body weight (BW) (g)	4° C	8° C	12 °C	16 °C	18 °C
Freshwater phase					
<0.3	ad libitum				
0.3–0.8	2.0	3.0	4.0	4.5	4.5
0.8–5.0	1.8	2.7	3.5	3.9	3.9
5.0–10.0	1.6	2.1	3.1	3.4	3.4
10.0–25.0	1.4	2.0	2.7	3.1	3.0
25.0–40.0	1.0	1.6	2.2	2.7	2.6
40.0–60.0	1.0	1.3	2.0	2.6	2.5
Seawater phase					
80–200	1.5	1.9	2.2	2.8	
200–300	1.3	1.9	2.3	2.6	
300–500	1.2	1.7	2.0	2.3	
500–775	1.0	1.4	1.7	2.0	
775–1 000	0.8	1.0	1.5	1.8	
1 000–1 250	0.7	1.0	1.3	1.5	
1 250–1 500	0.6	0.9	1.2	1.4	
1 500–2 000	0.5	0.7	1.1	1.2	
2 000–3 000	0.5	0.7	0.9	1.1	
>3 000	0.5	0.6	0.9	1.0	

Source: unpublished data of S.J. Kaushik.

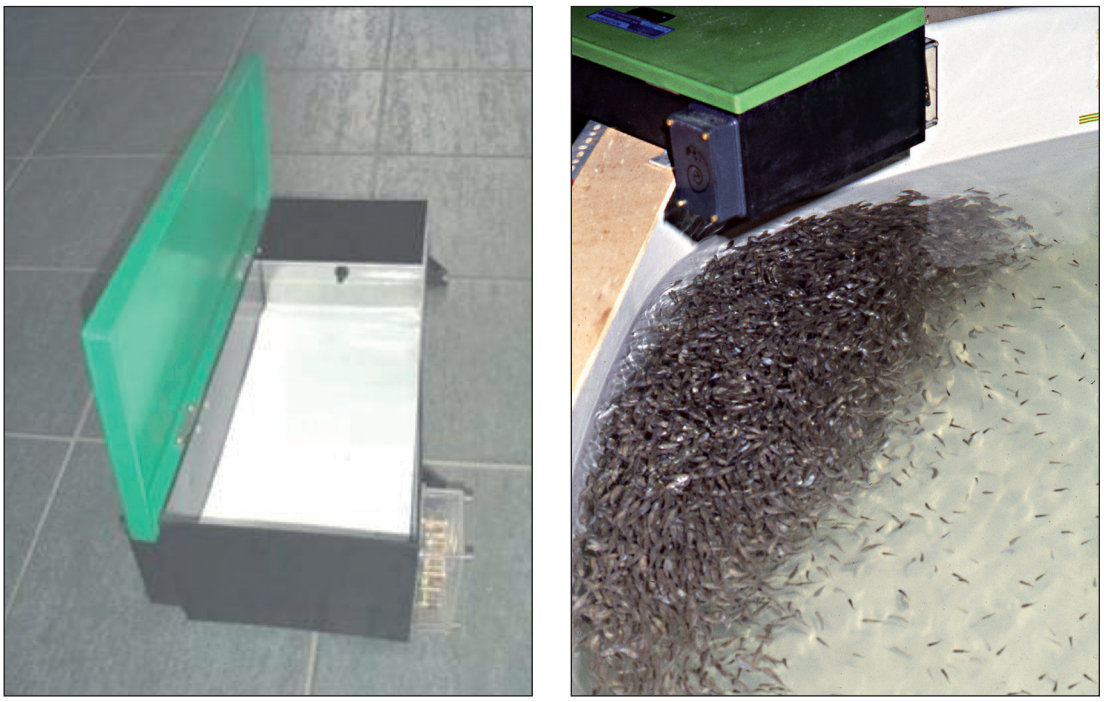
It is now established that trout and salmon fry should be weaned with starter feeds as soon as possible after their mouths become open. First-feeding fry are generally fed almost continuously, which requires the use of some kind of a feeding device. Utmost care is taken at this stage to maintain water quality and to avoid excessive feeding with too fine particles, which can adversely affect gill ventilation and filtering.

There are currently a number of quite sophisticated feed distribution systems for use in aquaculture. The choice will depend upon how well they are adapted to the species and size of fish being raised and to the culture site.

5.2.2 Belt-feeders

Belt-feeders are mostly utilized for the rearing of small fish (Figure 5). A given amount of feed is placed on a belt which slowly moves, dropping feed into the rearing tanks or basins. Feed is slowly and evenly released into the tanks. These feeders use a clock-work mechanism and are thus easy to use even in remote areas, since no electric power is required. The belt is pulled back to initiate functioning of the clock. The desired amount of feed is spread over the belt surface, either all along the belt or in clumps. These feeders can deliver between 3 and 5 kg of feed per tank, operating over either 12 or 24 hours to deliver feed over the full 24 hours of the day or only during the photophase (i.e. during daylight). Electrically operated belt feeders are used in indoor hatcheries.

FIGURE 5
Belt-feeder based on a clock-work mechanism used for rearing young fish (left: an empty belt-feeder and right: feed being delivered from the feeder)



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5.2.3 Mechanical feeders

Several types of automatic and mechanical feeders are available for trout farming, including electric, water-powered and solar-powered units with variable timers. There are feeders that use compressed air to blow feed out over the water surface at pre-set intervals, and truck or trailer mounted units that blow the feeds into the tanks

(Figure 6). Mechanical feeders based on vibrating systems deliver small quantities of a given amount of feed per delivery, the frequency of which can be adjusted. These are generally used for rearing small fish.

FIGURE 6
Two examples of mechanical delivery of feeds in a land-based rainbow trout farm

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5.2.4 Demand feeders

Demand feeders are widely used in freshwater rainbow trout farms (Figure 7), as well as on small cage sites for salmon farming (Figure 8). Feed is placed in cylindro-conical bins and below the feed container, a movable disc is attached and a pendulum or a rigid rod extends to, or somewhat below, the water surface. The disc acts as a plug to prevent feed from falling out of the bottom of the feeder. When a fish swims around and moves the pendulum, the disc is shifted and a small quantity of feed is delivered. There are several variants of the self-feeding trigger: fixed rod (as mentioned above), 'bite and pull' and even photosensitive triggers placed just below the surface of the water, the relative advantages or inconveniences of which are continuously being studied.

The amount of feed delivered with each movement of the rod is adjusted by positioning the disc vertically up or down the rod, resulting in a larger or smaller amount of feed delivery. Fixed-rod triggers can be placed just below the water surface, but accidental collisions with the trigger can increase feed wastage. This is prevented by enclosing the rod in a protective screen or placing the trigger just above the water surface. Generally, salmonids, and especially rainbow trout, learn to use the rods very quickly in order to get the reward.

The original studies on the capacity of fish to use self-feeders were undertaken nearly 50 years ago using goldfish as a model (Rozin and Mayer, 1961, 1964). Fish fed using demand feeders often display highly variable feeding activity, both within a day and across days. In rainbow trout and salmon, significant peaks in trigger-biting activity occur at dawn and dusk (Kadri *et al.*, 1991; Boujard, 1999). Depending on gastric evacuation rate and the return of appetite, peaks in trigger-activation activities can vary across days.

Studies have also been undertaken to understand the feeding activity and behaviour, especially with regard to the detection of differences in trigger activation by individual fish within a batch, using individually tagged fish or video observations. In some cases, after a few days of acclimation to the system, only one or two individuals account for almost all of the trigger-biting activity. Development of a dominance hierarchy, in which the dominant individuals monopolize the trigger and consequently grow better than the others within the group, has been observed in

FIGURE 7
A demand feeder used in a rainbow trout farm

COURTESY OF G. CHOUBERT, INRA.

FIGURE 8
A demand feeder used in the rearing of salmon in cages

COURTESY OF FAO/S.J. KAUSHIK.

the arctic char (*Salvelinus alpinus*) (Brännäs and Alanärä, 1993). However, whether or not this is a common phenomenon is not clear, since there appears to be much variation in feeding behaviour depending on the level of domestication of the species concerned. It is also reported that fish fed using demand feeders often display variable feeding activity over time. Bailey and Alanärä (2006) found that this variability was very much linked to differences in gut evacuation rates and the return of appetite.

Demand feeding systems have the advantage of taking into account the behavioural rhythms of the fish and the nutritional quality of the diet. There is accumulating evidence to show that other marine finfish grown in cages, as well as tropical fish reared in ponds, can adapt themselves to such demand feeders. Such devices also hold much promise for understanding the specific feeding rhythms of new aquaculture species and for obtaining quantitative data on the control of voluntary feed intake (VFI) as affected by dietary nutrients. The other benefit of demand feeders is that fish feed themselves according to their endogenous rhythms, resulting in low labour costs and little waste of feed, provided that the feeding device and the trigger are adjusted properly. Proper adjustment can also reduce aggressiveness within a group, reducing size variability.

5.2.5 Computer-controlled automatic feeding systems

Other types of mechanical feeders used in salmon and trout farming involve the use of tubes extending from feed bins or silos to each tank or sea cage. In land-based farms, these tubes are rigid structures that are permanently fixed to the tank or basin sides (Figure 9). For rearing trout or salmon in floating cages, such tubes are made of flexible material that floats on the water, connecting each cage to the feed storage bin (Figure 10). These devices have a balance for weighing a given amount of feed coming from the feed bin, and air pressure is used to blow the precise amounts of feed to each cage based on schedules defined by the farmer. In some farms, water instead of air is used as a vector to blow the feeds into the respective tanks or cages.

FIGURE 9
Feed distribution using an automatic feed delivery system in a land-based rainbow trout farm where feed is blown along with water

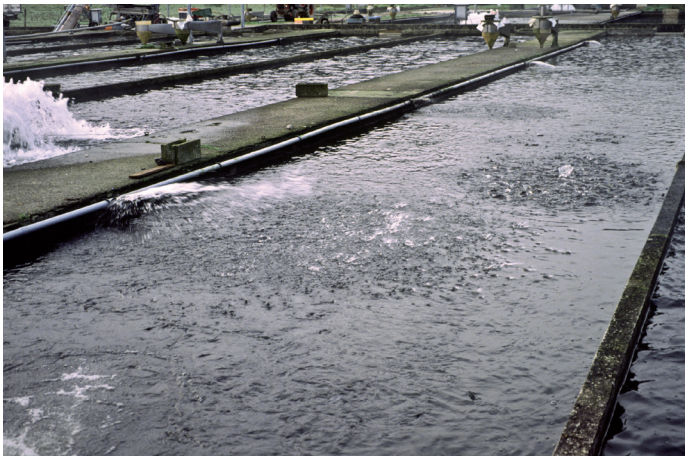

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FIGURE 10
Feed distribution using an automatic feeder for cage culture of Atlantic salmon near Bodo in Norway

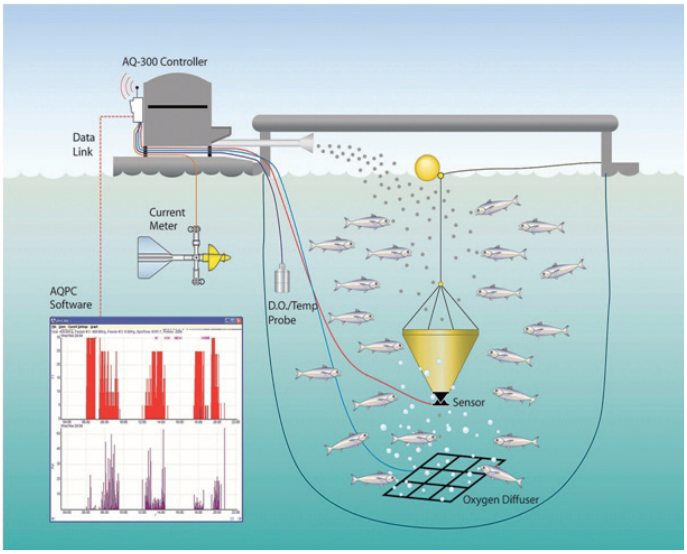
COURTESY OF TREVOR TELFER, UNIVERSITY OF STIRLING.

A number of developments have been made in automatic feed dispensing systems, especially with regard to the control of feed intake and the reduction of feed losses, using relatively sophisticated video sensors and computer-controlled feed delivery systems (Kadri and Blyth, 1997). Further innovations include pellet sensors allowing for feeding fish to satiety without any human intervention, delivering the correct amount of feed and especially avoiding as much as possible any uneaten feed.[3] Automatic feeders equipped with video monitoring systems or infrared sensors (Figures 11 and 12) have been tested extensively under both laboratory conditions (Kadri *et al.*, 1991) and field situations of cage rearing of Atlantic salmon and rainbow trout. Data of Noble *et al.* (2007a) under cage-culture conditions show that Atlantic salmon parr may shift their daily feeding rhythms with season, exhibiting a morning peak in late summer and a midday peak in winter. Using self-feeders with specific devices, these authors could show that daily ration varied between day and season, decreasing from autumn to winter and increasing in spring, and that this was related to both temperature and change in day length.

[3] www.akvagroup.com/index.cfm?id=202454

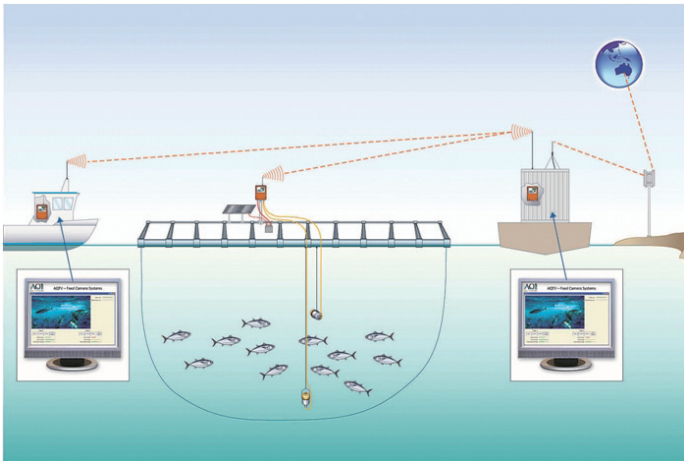
From a scientific point of view, the self-feeding capacity of fish gives us the opportunity to determine feed preferences, not only as a direct function of palatability of feeds but also as influenced by the physiological status and environmental conditions of the fish. In any case, a diet should cover not only the nutrient requirements but should also be palatable and ingested in sufficient quantities to ensure optimal growth. Maximum growth and feed conversion depend on avoiding over- and under-feeding of fish. Feeding in excess of voluntary appetite causes waste, environmental pollution and higher feed conversion ratios (FCR).

FIGURE 11
Infrared sensor-based feeding control system



COURTESY OF S. KADRI, UNIVERSITY OF GLASGOW.

FIGURE 12
Digital feed camera systems



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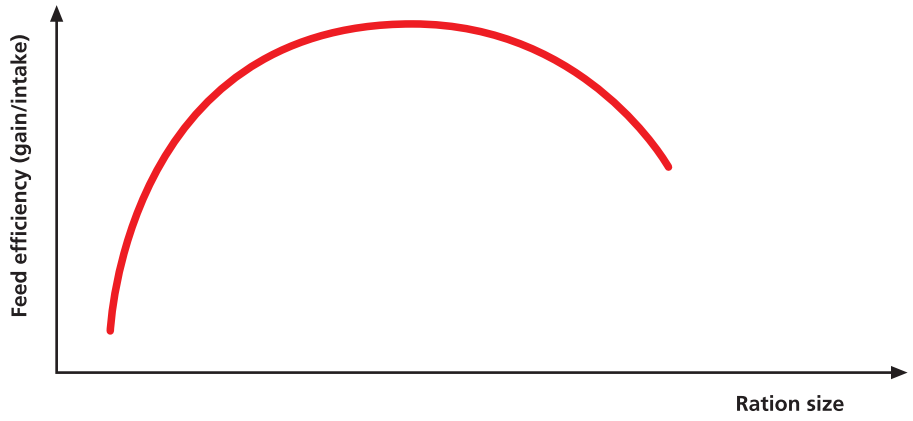
6. DERIVING FEEDING TABLES, FREQUENCIES AND SCEDULES

6.1 Feed allocation

Since growth strongly depends on the amount of feed supplying all the essential nutrients and energy, maximum growth rate is attained by feeding fish at satiation level. When access to feed is restricted or the ration size is reduced, increased size heterogeneity due to social hierarchies appears within the group (Jobling, 1983; McCarthy, Carter and Houlihan, 1992; Brännäs and Alanärä, 1993; Houlihan, Boujard and Jobling, 2001).

Under- or over-feeding, on the other hand, can lead to reduction in feed efficiency (Figure 13). From a practical point of view, in order to optimize ration levels, fish farmers generally rely upon feeding charts provided by feed manufacturers (Table 6; NRC (1993). Often, the farmers themselves empirically derive feeding charts, generally by predicting weight gain and assuming feed efficiency levels based on past history of farm husbandry and performance. A special caution is always issued with such feeding charts stating that they are applicable to a given type of feed and that adjustments will have to be made depending on the type of feed, husbandry conditions, genotype and other environmental factors. Feeding standards should be based on energy and nutrient requirements (Cho, 1992).

FIGURE 13
Theoretical relation between ration size and feed efficiency



Source: Kaushik (2000).

During the last 20 years, proposals have been made to derive specific feeding charts based on nutritional bioenergetic principles. The underlying principles have been detailed in a number of papers (Cho and Kaushik, 1990; Cowey and Cho, 1991; Cho, 1992; Cho and Bureau, 1998). The first condition is that for each species, precise growth prediction is made under given temperature conditions, using temperature growth coefficients for that particular species or genotype. Based on the expected weight gain over a period of time, the expected whole body nutrients and energy gain (RE = retained energy) is determined. Based on the predicted weight gain, allocation of expected maintenance energy requirements (HEf = heat expenditure under fasting) as affected by water temperature and body mass are determined. The energy expenditure due to feed intake (HiE = heat increment of feeding) is calculated. The non-faecal or metabolic energy losses are estimated (retained energy – maintenance need – heat increment of feeding). The minimum digestible energy (DE) required to achieve this growth and body composition is then estimated. Once the DE needs are known, the feed allowance can be made, provided data on the DE levels of the feeds are available. The basic idea behind this concept is that the voluntary feed intake (VFI) is driven

by DE needs. Recent research data strongly suggest that this general principle is also applicable to different finfish and to a certain extent, also to shrimp. For salmonids, computer software to estimate feed requirements and to devise feeding tables based on such bioenergetic principles have been developed (Cho and Bureau, 1998) and models developed (Cho, 2004). Such procedures have also been validated with non-salmonids (Kaushik, 1998). The general principles are given in Table 7.

TABLE 7
Evaluation of DE and feed requirements

Evaluate Thermal Unit Growth Coefficient (TGC)	TGC = ($W_f^{1/3} - W_i^{1/3}$) / sum degree days (= T x days)
Predict weight gain (WG)	WG = ($W_i^{1/3}$+ (sum degree days x TGCs)^3
Predict Retained Energy (RE)	RE = ($W_f - W_i$) x %DM x kJ per g DM
Maintenance energy needs (Hef)	
(Hef, in fasting fish, kJ day^{-1}), example for trout	HEf = [(–1.04+3.26*T–0.05*T2)*kgBW$^{0.824}$]
Heat increment of feeding (HiE)	HiE= HEf x O.6
Non-faecal energy losses (NFE)	NFE = (RE+HEf+HiE) x 0.06
Calculate total Digestible Energy needs	(DE) DE = RE + HEf + HiE + NFE
Calculate feed required	Feed = DE needs x dietary DE^{-1}

Notes: W_f = final body weight; W_i = initial body weight; DM = dry matter; T= temperature in °C; BW = body weight; DE = digestible energy.
Source: Based on Cho (1992) and Kaushik (1998).

Such principles are also being applied by feed companies to devise feeding tables and by well-trained farmers for application in the field. In the absence of data on dietary DE levels and on DE needs per unit gain of a given species, a very practical alternative is to let the fish eat to satiety by themselves, using demand feeders.

6.2 Frequency of feeding

It is recognized that all fish should be fed to apparent or visual satiation. The frequency of feeding is governed by two major factors, both of which affect the rate of passage of foodstuffs through the digestive tract (Elliott, 1982). With increasing water temperature, the transit rate is increased and so is the feeding frequency. With increasing body mass/length increment, the transit rate is reduced and consequently, the frequency of feeding is reduced. Thus for first-feeding fish, the feed is provided continuously over the day. Subsequently, as fish grow, the frequency is reduced to eight times per day. Once fish reach 1–2 g, feeding frequency is often brought to four to five times per day, moving to three times per day when fish reach ~5 g. Studies with different salmonids have shown that above 20 g body mass and under standard environmental temperature conditions, a feeding frequency of twice a day to apparent satiation is sufficient (Luquet, Renou and Kaushik, 1981). Even under maintenance conditions, the frequency of feeding can affect nitrogen and energy utilization (Kaushik and Gomes, 1988).

If the feed allocation is insufficient, increasing the number of meals does not bring any further advantage. For instance, in post-smolt Atlantic salmon, increasing the feeding frequency to up to 80 times per day while keeping the daily food ration fixed does not seem to give any better growth rate or any decrease in size variation (Thomassen and Fjaera, 1996). Similarly, in juveniles of rainbow trout, increasing the number of meals inconsiderately (up to 32 meals a day) leads to poor growth performance (Linner and Brannas, 2001). As mentioned above, the frequency of feeding should not only take into account the transit rate of feedstuffs in the digestive tract but also give due consideration to the overall feed allocation per unit distribution. For instance, if the number of pellets delivered at a meal is far less than the number of fish in the tank or cage, this naturally leads to some fish not being able to have access to feed, leading to differences in growth within the batch.

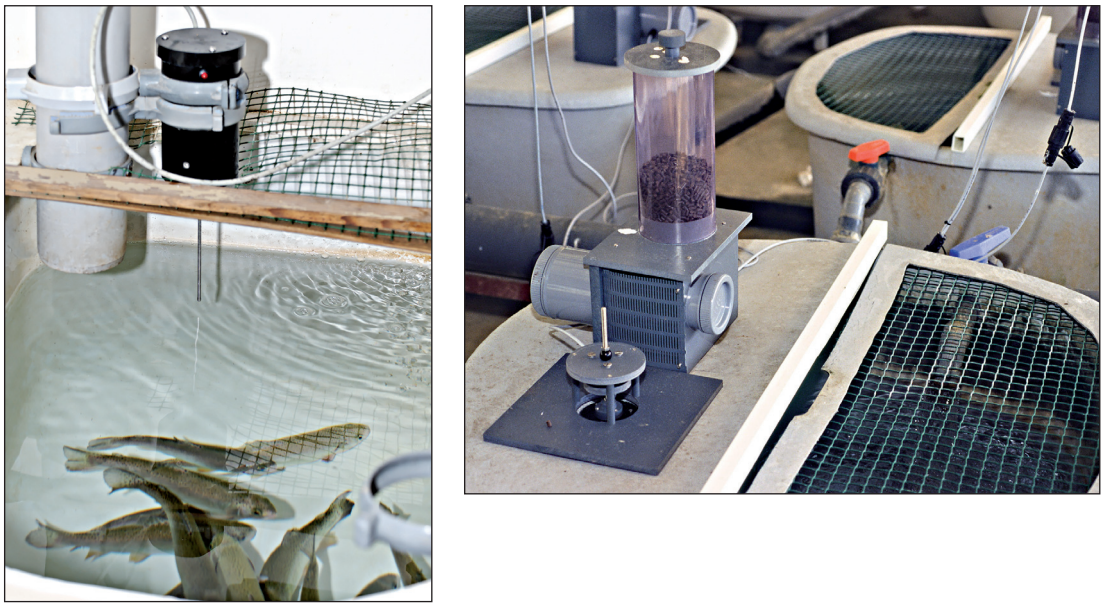
6.3 Time of feeding

Since each species can have an endogenous feeding rhythm controlled by the central nervous system and the entraining endocrine factors and governed by environmental cues (especially photoperiod), much work has been undertaken to understand the feeding rhythms in farmed fish (Boujard, 1999; Madrid, Boujard and Sanchez-Vazquez, 2001). Even the timing of a single meal can influence feed intake, growth and nutrient utilization. For example, Boujard, Gelineau and Corraze (1995) found that compared to feeding at dawn, feeding totally out of phase with the endogenous rhythms of rainbow trout (i.e. at other hours of the day or at midnight) led to poor feed intake and lower protein or energy utilization. More recently, Noble *et al.* (2007d) evaluated the effects of different self-feeding regimes on performance and welfare of rainbow trout by feeding them either (i) a single meal at dawn of three hours duration; or (ii) three meals at dawn, midday and dusk of two hours duration each; or (iii) by giving continuous access to feed over a 12 hour period during the day. These authors did not find any significant differences in ration size, growth rate, condition factor, size heterogeneity, food wastage or feed efficiency between the different groups, although the levels of aggression (as evidenced by increased fin erosion) were highest in trout fed only a single meal, Similar data have also been obtained with Atlantic salmon (Noble *et al.*, 2007b, c).

6.4 Circadian rhythms of feeding

Using computer-controlled 'eater meter' devices specifically developed for the purpose of analyzing feeding rhythms, feeding activities and food preferences (Boujard *et al.*, 1992; Blyth, Purser and Russell 1993; Figure 14), circadian rhythms of feeding have been analyzed in several species with different ecological niches and feeding behaviours (e.g. cyprinids, salmonids, cichlids, silurids) under controlled conditions with free access to food (Boujard, 1999). All studied species showed rhythmic patterns of feeding activity, with diurnal or nocturnal peak activity (acrophase). Some species, e.g. European sea bass and common carp (*Cyprinus carpio*), are able to phase shift their rhythm of feeding from nocturnal to diurnal

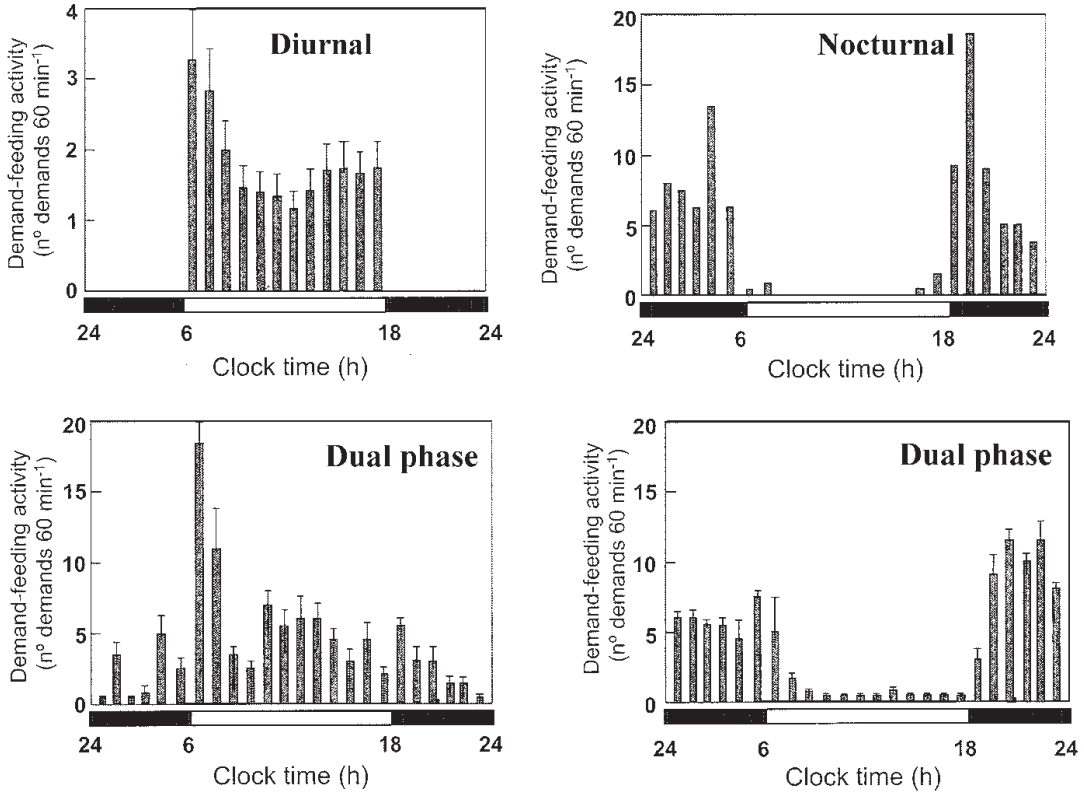
FIGURE 14
Eater-meter device used for experimental studies for monitoring feeding behaviour, feeding rhythms and feed preferences in fish



COURTESY OF FAO/S.J. KAUSHIK.

and *vice-versa*, showing some plasticity in behaviour and adaptation to changing conditions (Madrid, Boujard and Sanchez-Vazquez, 2001; Figure 15). Feeding activities are sometimes linked to endocrinological parameters and sometimes dissociated, and our understanding of the exact cues, environmental or otherwise, governing such rhythms are far from clear.

FIGURE 15
Patterns of demand-feeding activity exhibited by different species of fish



Source: Redrawn from Madrid, Boujard and Sanchez-Vazquez (2001).

6.5 Physiological mechanisms underlying feed intake

Within a given species, voluntary feed intake (VFI) will also vary depending upon the physiological status (e.g. during gametogenesis). It is well established that feed intake per unit body weight decreases with increasing body weight and increases with increasing water temperature within the thermal preferendum zone of a given species. Under stressful conditions such as hypoxia or high ambient ammonia levels, the VFI is also reduced.

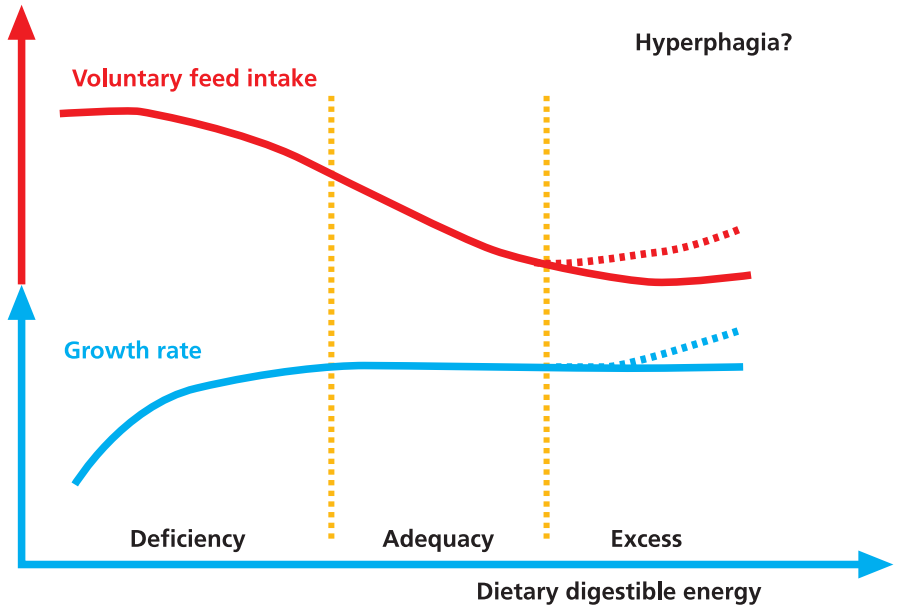
The central role of the brain and the integrative or feed-back mechanisms involved in feed intake regulation has been stressed in most farm animals (Forbes, 1986). In fish, the exact involvement of the central nervous system in the control of appetite, satiety and feeding activity is only slowly being discerned. It is in fact even difficult to discern the notions of appetite or hunger in fish as with terrestrial animals. The role of the hypothalamus in the control of appetite and satiety, although established, implies a number of factors which can be divided into two categories, orexigenic (those which stimulate feeding) and anorexigenic (those which inhibit feeding). The involvement of neuropeptides such as Neuropeptide Y (NPY), orexins, galanin, agouti-related protein (AgRP), ghrelin, cholecystokinin (CCK), cocaine amphetamine-regulated transcript (CART), and corticotropin-releasing factor (CRF) are now being recognized as having

similar orexigenic or anorexigenic actions in fish as in other animals (Nakazato *et al.*, 2001; Volkoff *et al.*, 2005). There are also indications that leptin might play a role in feed intake and energy homeostasis in the arctic char, as suggested by Froiland *et al.* (2010).

Our knowledge of the physiological control of feed intake of fish under farming conditions is mainly concerned with some environmental and biotic factors and to a lesser extent with a few dietary and nutritional factors. As regards nutritional factors, the prevailing idea that fish, like other animals, eat to satisfy their energy requirements, provided the feeds are adequate in all nutrients (Kaushik, Luquet and Blanc, 1981; Cho and Kaushik, 1990; Bendiksen, Jobling and Arnesen, 2002) remains valid. Even in their very early studies, Rozin and Mayer (1961) found that goldfish increase their food intake significantly in response to dilution of their normal diet with kaolin, appearing thus to eat for energy or nutrient value. Similar findings were also noted for European seabass fed diets supplemented with bulk agents (Dias *et al.*, 1998).

However, whether or not rainbow trout and salmon are subject to hyperphagia due to feeds with high fat and consequently high DE content remains a question of practical interest (Figure 16). While most data indicate that digestible energy is the factor limiting voluntary feed intake, there are also suggestions that other factors such as protein content, amino acid profile, orosensorial agents or post-absorptive metabolic control play significant roles. Based on what is known in terrestrial animals, two main theories behind appetite regulation – the 'glucostat' and the 'lipostat' mechanisms, both involving a central role of the hypothalamus, have also been analysed to a small extent.

FIGURE 16
Schematic relation between dietary energy supply and growth or feed intake



Source: Unpublished data of S.J. Kaushik.

The 'glucostat' theory implies the involvement of whole body glucose mass and the receptivity of the hypothalamus to such signals as regulating feed intake and appetite over the short term. In fish, data available today are very contradictory. In fact, under conditions of fasting as seen in migrating salmon, plasma glucose levels are higher than in fed fish (Sheridan and Mommsen, 1991). This is also seen in rainbow trout with high plasma glucose levels when fed feeds with low protein levels (Kirchner, Kaushik and Panserat, 2003). It appears then that the glucostat control of VFI is not operating in fish and if at all, it has little impact on feed intake over long periods.

The 'lipostatic' control is recognized as having a cumulative effect over time, affecting VFI over long periods and can thus have an effect on body mass gain. The accumulation of fat with increasing body mass can send satiety signals (leptins or other hormones) that suppress the feeling of hunger and thus reduce feed intake and maintain body mass. Whether such a mechanism operates in fish has been the object of a few studies. There is some evidence in fish that large fat stores reduce VFI over the long term (Jobling and Miglavs, 1993; Silverstein *et al.,* 1999; Ogata & Shearer, 2000; Regost *et al.,* 2001, Jobling *et al.,* 2002; Bendiksen, Jobling and Arnesen, 2002; Johansen, Ekli and Jobling, 2002; Johansen, Sveier and Jobling, 2003; Shearer, Silverstein and Plisetskaya, 1997).

Bendiksen, Jobling and Arnesen (2002) observed that Atlantic salmon parr compensated for differences in feed energy densities to maintain energy and nutrient intakes, and that lipostatic factors may be operating to regulate feed intake and growth.

Based on such ideas, attempts have also been made to tailor salmon body composition by diets varying in digestible protein to digestible energy ratios ranging from 16 to 26 g/MJ and by phase feeding the different diets over long periods. Morris *et al.* (2003) found that the confounding effects of season- and size-related increases in inter-individual variability made it difficult to tailor the yield or body composition of Atlantic salmon simply by conservative changes in the gross composition of the feeds.

Jobling and Johansen (1999) hypothesized that since there is an increased fat deposition in fish undergoing a period of nutritional restriction and subsequent catch-up growth when feed supply is restored, there might also be a lipostatic control of feed intake in salmonids. Subsequent studies by Johansen, Ekli and Jobling (2002) and Johansen, Sveier and Jobling (2003) were undertaken to test whether the lipostatic control of feed intake operates in juvenile Atlantic salmon, first by manipulating body fat content through feeds with low or high fat levels and then by challenging the lean and fat fish with the high- and low-fat feeds simultaneously. After an initial period of adaptation, body compositions converged among treatments and differences in feed intake reduced, providing some evidence for a lipostatic regulation of feed intake.

Subsequent studies by Geurden *et al.* (2006) undertaken with rainbow trout fed one of three diets having variable protein and fat levels showed that, under self-feeding conditions, fish of similar body mass had similar VFI without apparent compensation in terms of overall energy intake. Rainbow trout fed the high-fat diets had high body fat deposition but similar protein growth. The absence of any change in VFI in trout fed the high-fat diet suggests a low negative feedback by fat intake or by body fat content. Based on their observations of similarities in lean body growth, these authors favoured the idea that growing trout would regulate their VFI in order to meet the demand for maximal protein growth rather than to satisfy a predetermined energy requirement. Such concepts need to be verified in detail in fish generally confronted with feeds of varying nutrient content under farming conditions.

7. LESSONS LEARNT FROM SALMONIDS: APPLICATION TO TROPICAL AQUACULTURE

Tropical finfish farming has been growing at a relatively high rate. For instance, the production of tilapias has been increasing by about 10 percent per annum and that of milkfish by 4 to 5 percent (FAO, 2012). Production of other species such as the Indian major carps - catla (*Catla catla*), rohu (*Labeo rohita*) and mrigal (*Cirrhinus cirrhosus*) - has also been increasing. Although there are indications that the farming of these species is undergoing increased intensification, it is as yet difficult to estimate the exact amount of compound complete feeds that are being used for species such as the Chinese and Indian major carps, tilapias, milkfish, mullets and groupers.

7.1 Nutrient requirements

Of all the species mentioned above, data on nutrient requirements for all the essential nutrients are available only for common carp (Takeuchi, Satoh and Kiron, 2002), tilapias (Shiau, 2002) and, to a certain extent, for barramundi (*Lates calcarifer*) (Boonyaratpalin and Williams, 2002), milkfish (Lim, 1991; Borlongan and Coloso, 1993) and Indian major carps (Murthy, 2002). For other species, even those grown in large amounts (e.g. catfish in Viet Nam, major carps in the Indian subcontinent), nutrient requirement data are very limited. For instance, a commonly used essential amino acid (EAA) requirement profile for these fish is the one proposed by Ogino (1980) for carp and trout. This profile is also used for evaluating the essential amino acid content for a score of ingredients, as was done by Tacon, Metian and Hasan (2009). As far as essential amino acids are concerned, this in itself is not of serious concern, since there is a high degree of homogeneity between the amino acid profiles and requirements of different species (Cowey, 1994; Mambrini and Kaushik, 1995; Wilson, 2002; Kaushik and Seiliez, 2010).

The amino acid profile proposed by Ogino (1980) is based on the principle that since the main purpose of dietary protein/amino acid supply is to increase whole body protein accretion, one can calculate the requirements based on daily increments in the whole body protein-bound amino acids. It then appears that the ideal protein would be the one which reflects the whole body IAA profile of the corresponding species. The whole body protein-bound amino acid profiles are very similar among different species of teleosts or crustaceans (Table 8), and the amino acids deposited during growth can hence be considered to be similar. However, for essential fatty acids and micronutrients, data are sparse (Sargent, Tocher and Bell 2002; Kaushik, 2004), whereas these nutrients play a major role in growth as well as in maintaining the health and physiological well-being of fish. It is clear that the generation of a solid nutrient requirement database for all species of interest is essential.

TABLE 8

Whole body amino acid composition of different finfish and crustaceans (expressed as g/16 g N)

Amino acid	Finfish	Shrimp
Alanine	6.17 ± 0.82	4.86 ± 0.56
Arginine	6.16 ± 0.98	6.59 ± 1.20
Aspartic acid	9.19 ± 0.85	8.37 ± 0.34
Cystine	0.96 ± 0.26	0.78 ± 0.11
Glutamic acid	14.29 ± 2.49	12.55 ± 1.20
Glycine	6.81 ± 1.69	5.03 ± 1.32
Histidine	2.47 ± 0.63	1.85 ± 0.17
Isoleucine	4.29 ± 0.92	3.56 ± 0.32
Leucine	7.20 ± 0.70	6.13 ± 0.47
Lysine	7.38 ± 0.89	6.42 ± 0.51
Methionine	2.75 ± 0.45	2.18 ± 0.17
Phenylalanine	4.10 ± 0.47	3.44 ± 0.27
Proline	4.37 ± 1.13	3.13 ± 0.39
Serine	4.15 ± 0.47	3.27 ± 0.29
Threonine	4.39 ± 0.54	3.18 ± 0.14
Tryptophan	1.01 ± 0.29	0.90 ± 0.19
Tyrosine	3.02 ± 0.62	3.30 ± 0.40
Valine	4.73 ± 0.53	3.95 ± 0.61

Source: Kaushik and Seiliez (2010).

7.2 Use of formulated feeds

As mentioned above, we also do not have a clear idea of how much formulated complete feed is being used in tropical fish farming, despite attempts such as those by Tacon, Metian and Hasan (2009). There is a wide variety of studies showing that the correct use of adequately formulated feeds leads to improved net returns in terms of nutrients (e.g. nitrogen, phosphorus) as well as to economic benefits as compared to extensive or semi-intensive farming practices using mixtures of ingredients that are generally termed 'farm-made aquafeeds'. In almost all tropical finfish studied so far, there are clear indications that the use of formulated pelleted feed leads to better economic returns. By using balanced supplementary feed in conjunction with correct management of pond productivity, Tripathi *et al.* (2000) could achieve a production of more than 12 tonnes of Indian major carps per hectare. The benefits of using pelleted complete feeds for growing rohu in unfertilized ponds have been demonstrated (Anand, Manomaitis and Ramesh, 2006). Even very early studies with milkfish have shown that supplemental feeding can improve production and economic returns (Sumagaysay, Marquez and Chiu-Chern, 1991). Increase in tilapia production is also undoubtedly due to the use of complete feeds. The advantages of feeding groupers with formulated complete dry feeds have also been demonstrated (Bombeo-Tuburan *et al.*, 2001; Sim *et al.*, 2005; Rachmansyah, Palinggi and Williams, 2009). Studies on the feeding habits of mullets and the development of artificial feeds have been conducted for many years (Vallet *et al.*, 1970; Albertine-Berhaut, 1973), and there is continuing interest in developing feeds using plant ingredients, algae or yeast (Wassef, El Masry and Mikhail, 2001; Luzzana *et al.*, 2005).

One major constraint to adopting formulated feeds is that these feeds should be formulated using basic nutritional principles, meeting the requirements of the target species, and taking into account the specific farming systems. Given that a number of species of mullet and grouper are farmed, our knowledge on the nutritional requirements of these species is very limited. Since Kaushik (1998) proposed that the bioenergetic principles initially developed and applied to salmonids are applicable also to non-salmonids, such an approach has been applied with success for gaining insight on protein and energy requirements and for formulating feeds for groupers (Lupatsch, Kissil and Sklan, 2003; Lupatsch and Kissil, 2005) and barramundi (Glencross, 2006). Given the issues of the availability and cost of fishmeal and fish oil at the global level, the achievements made with salmonids can be easily extended to these species.

7.3 Feed form and quality

In terms of feed quality, the relative advantages of using dry feeds as compared to trash fish or moist feeds are as valid for tropical species as for salmonids. While it is still common to use mixtures of ingredients (e.g. cereal bran + oil cakes), the use of pelleted feeds is becoming more common, and the same constraints regarding the nutritional and physical characteristics of feeds apply.

It has often been considered that dry diets are inadequate to feed small fish larvae during the first stages of feeding, and that such diets could be used successfully only after the larvae had been fed on live food for some time ('weaning'). However, after more than 20 years of research, considerable progress has been made in the development of starter feeds and a feeding system for first-feeding cyprinid larvae (Charlon and Bergot, 1984; Charlon *et al.*, 1986). Since then, this possibility has been demonstrated in a number of species, including European seabass (Cahu *et al.*, 1998). The development of nutritionally complete feeds having feed particle size corresponding to the size of the larvae (Table 9) or the diameter of the buccal opening and an efficient way of feed distribution in a more or less continuous manner (Figure 17) can be applied right from first-feeding onwards to grow the larvae of many fish. Besides the system as presented by Charlon and Bergot (1984), belt-feeders can be used to grow these larvae with

formulated complete feeds. Indeed such studies have even led to the development of semi-purified diets for first-feeding larvae and to the evaluation of the nutrient requirements of first-feeding larvae of carp (Gouillou-Coustans, Bergot and Kaushik, 1998) and European seabass (Mazurais *et al.*, 2008). Similar progress can be made with many of the tropical species. Another major advantage is that of producing good-quality fry or juveniles for on-growing in the farms.

TABLE 9
Species of fish in which larvae have been shown to grow well using solely inert dry formulated complete feeds from first-feeding onwards

Species	Temperature (°C)	Size at first meal (mm)	Dry feed intake
Grayling, *Thymallus thymallus*	8–12	10–12.5	yes
Siberian sturgeon, *Acipenser baeri baeri*	17–20	11–13	yes
European whitefish, *Coregonus laveratus*	12–14	10–12	yes
Allis shad, *Alosa alosa*	10–22	10–11	yes
Wels catfish, *Silurus glanis*	24	9–10	yes
North African catfish, *Clarias gariepinus*	25–28	7	yes
Common carp, *Cyprinus carpio*	24	6–7	yes
Goldfish, *Carassius auratus*	24	5.5–6.5	yes
Pike-perch, *Sander lucioperca*	17–18	5–6	yes
European seabass, *Dicentrarchus labrax*	15–20	3–4	yes
Gilthead seabream, *Sparus aurata*	20–22	3	yes

Source: Unpublished data of S.J. Kaushik.

FIGURE 17
Automatic feed dispenser developed for rearing larvae with dry feeds right from first-feeding

COURTESY OF D. BAZIN, INRA.

Switching from traditional feeds to formulated feeds also requires adequate feeding and feed management practices that take into account the endogenous feeding rhythms of the species concerned. Changes in patterns of feed intake as observed in salmonids are also seen in other species, each of them showing distinct patterns (Talbot, Corneillie and Korsoeen, 1999). In stinging catfish (*Heteropneustes fossilis*), Sundararaj, Nath and Halberg (1982) showed that both feed intake and weight gain are maximal during the daily dark phase. In tilapia grown under laboratory conditions, the locomotor activity is diurnal whereas the feeding activity appears to be nocturnal (Fortes-Silva *et al.*, 2010). Under self-feeding conditions, many species of fish also appear to have reduced stress (Endo *et al.*, 2002).

7.4 Feeding systems

Under pond-culture conditions, or even in cages, it is difficult to control feeding to satiety for all fish when hand-feeding is used. Feeding fish some given proportion of body mass is also subject to error, given that the construction of such tables has little scientific basis. Full recognition of the endogenous feeding patterns, and taking complete advantage of such biological rhythms, can be used to control feed intake more effectively and to avoid feed wastage, a major concern in terms of economics and environmental quality. Feeding strategies should also aim at minimizing competition for feed within a group and thus arrive at homogenous group performance.

Simple self-feeding (demand) systems based on bamboo poles with feed-bags are already being used in the pond-culture of Indian major carps, for example (Figure 18). Sophisticated techniques using hydrophone sensor-based feeding systems have also been developed to control feed intake in pond aquaculture (Figure 19). It is also becoming increasingly evident that using feeds with the right buoyancy properties (i.e. floating feeds) can be an excellent tool in feed management, in as much as the feed distribution can be monitored (Figure 20). Such extruded floating feeds, although not containing lipid levels as high as those used for salmonids, can improve starch digestibility and reduce fines and possibly some anti-nutritional factors. In the absence of such self-feeding systems, application of bioenergetic principles should become standard practice to derive feeding charts based on the nutritional value of feeds and the requirements of the species under specific farming conditions. This will address and possibly eliminate the major question: "are we feeding the fish or the ponds/cages?"

FIGURE 18
Simple demand-feeder (left);
Bamboo poles with feed-bags used as demand feeders in pond culture of major carps (right)

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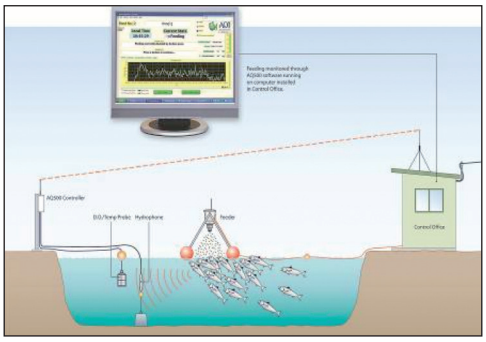
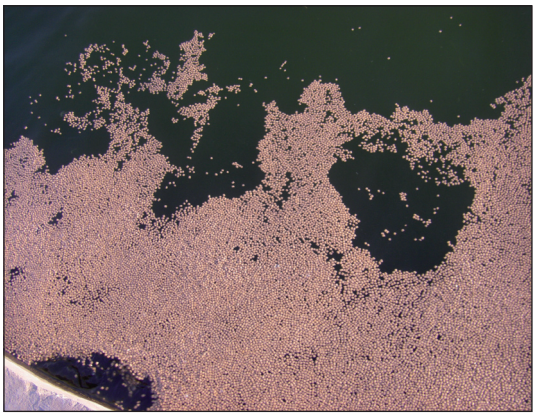
FIGURE 19
Diagram and photo of hydrophone feeding control systems:
sensor-based feeding control for pond aquaculture



COURTESY OF D. BAZIN, INRA.

FIGURE 20
Floating feeds can be a very useful management tool for controlling feed intake



COURTESY OF FAO/S.J. KAUSHIK.

Notes: left: floating feeds used for Indian major carp reared in ponds; right: floating feeds for rearing Nile tilapia in a land-based farm in Egypt.

8. CONCLUSIONS

At a stage when much focus is given towards the sustainability of fish farming, especially with regard to the correct allocation of feed resources, feed-based aquaculture is receiving increased public attention. Bioeconomic analyses are in favour of fish farming based on strong scientific evidence and applied nutrition for sustainable aquaculture development. In this context, correct feeding strategies are indispensable, and the experience gained with salmonids can well be applied to other species.

Feed distribution should ensure adequate nutrient supply to the whole group to achieve homogenous group performance. Good feed management practices should allow a reduction in feed/nutrient losses and reduced labour costs and/or manpower. Feeding strategies should be adapted to the biological rhythms of the target species. Feeding tables should be developed on a scientific basis, in order to meet the nutrient/energy requirements for specific production characteristics.

Much progress has been made in salmonids in the development of nutritionally adequate feeds, as well as in the physical characteristics of feeds through improved feed manufacturing processes. Progress made in improving feed and nutrient utilization efficiencies has also been supported by improvements and specific methods of feed delivery that avoid feed wastes, thus reducing environmental impacts. There is also clear evidence from comparative studies that similar progress can be achieved with other finfish species; indeed, such methods are already being practiced, for instance, in the Mediterranean area for the farming of European seabass and gilthead seabream. The principles behind these methods and the practical approach adopted by the feed industry and the farmers are very much applicable to tropical aquaculture conditions, where similar pressures exist with regard to improving feed efficiency and reducing financial and environmental burdens.

Despite the progress made in salmon and trout farming, even in salmonids it is still felt that more standardized test methods and automatic feeding systems are required by the farming industry. Lack of control of feeding can have adverse effects on the environment, increase costs for the farmer and lead to other effects, such as attracting wild fish from the neighbouring environment. All efforts should be made to avoid feed and associated nutrient losses into the environment. Under cage-culture conditions, feeds should be highly digestible and feed distribution adequate to obtain homogenous group growth performance, and the resulting faeces should not accumulate under the cages. In land-based farming systems, the faeces produced should be decantable and easily collected in order that they are not released into the natural waters.

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Environmental consequences of poor feed quality and feed management

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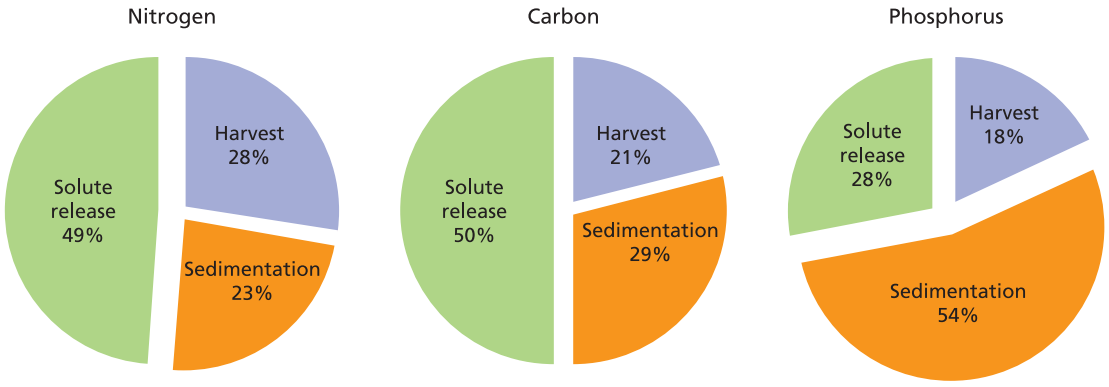
ABSTRACT

Feed costs account for up to 60 percent of total production costs, and inappropriate feeding and feed management can therefore be detrimental to the profits of farmers. Optimal feed management includes the use of well-balanced feeds covering the nutritional and energy requirements of the species and cost-efficient feeding regimes. The large variation among generally poor industrial feed conversion ratios (FCR) obtained in some fish production in Asia (such as milkfish, *Chanos chanos*) is a clear indication of inappropriate feeding. The accurate determination of the basic nutritional requirements throughout the production cycle and best practices in feeding regimes and technology is required in order to achieve a significant reduction in production FCR values. Specifically, the optimum dietary protein and energy levels, which are crucial parameters for effective feed formulation, need to be determined and evaluated on the farm. In addition, better knowledge is required for the main influencing biotic and abiotic factors, which are fish size, diet composition, feeding level and frequency, and water temperature and oxygen levels. The cost-efficient use of diets with formulations targeting the specific seasonal and developmental needs of the fish will effectively improve production FCR and have a significant economic benefit for aquaculturists. Optimizing feed utilization efficiency, fish growth, health and welfare, besides promoting production efficiency and economy, will also have a significantly positive environmental impact. Overfeeding results in excess nutrients entering the environment that need to be assimilated or they will accumulate. The paper includes a case study in the Philippines where poor feed quality and poor feeding practice for milkfish cage culture has had major environmental impacts on water and sediment quality.

1. IMPACT OF AQUACULTURE ON THE ENVIRONMENT

Aquaculture produces wastes that may negatively affect the environment. In intensive aquaculture where feed is given, a considerable amount of organic wastes are produced in the form of particulate (mainly uneaten food and faeces) and soluble substances (excreta) that increase biochemical oxygen demand and the concentration of dissolved nitrates and phosphates. Only a small proportion of the feed that is fed is taken up in fish production. Around 50 percent of the total nitrogen (N) and total carbon (C) is

FIGURE 1
Proportion of nutrients taken up in fish production and released into the environment

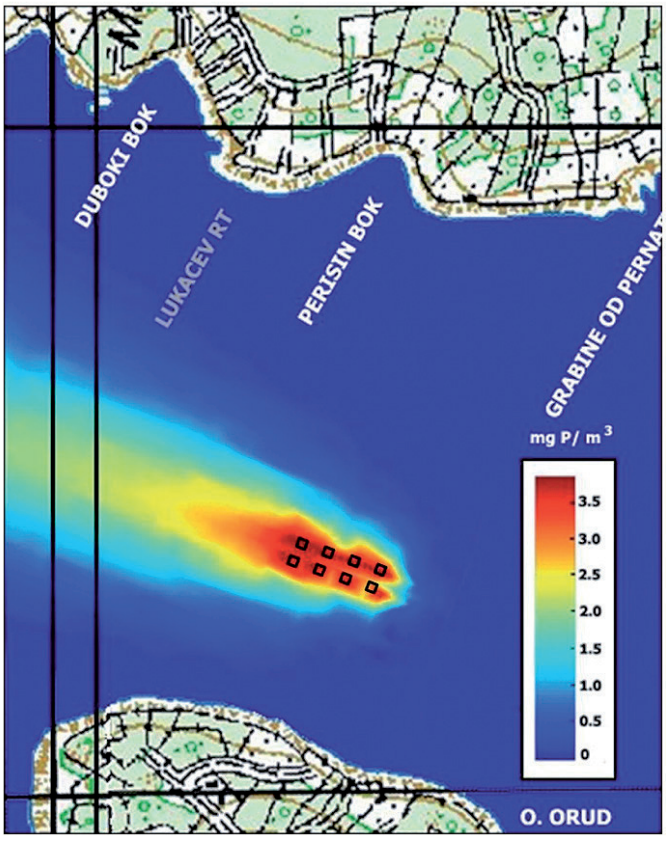


Source: Holby and Hall (1991); Hall *et al.* (1992).

excreted by the gills and dissolves into the water column, and over 50 percent of the total phosphorus (P) is released as particulate matter and settles on the sea bed (Figure 1).

Poor feed quality and poor feeding strategy have major influence on the environmental impact from shore-based and open-water farming systems. Excess nutrients not utilized by the fish or shrimp are released into the environment and have to be assimilated or they accumulate. Whether a nutrient becomes a pollutant in an aquatic system or not depends on whether it is a limiting nutrient in a given environment, and on its concentration and the carrying capacity of that ecosystem. In freshwaters, phosphorus is typically the limiting nutrient (Hudson, Taylor and Schindler, 2000), so its addition will dictate the amount of primary production (algal growth). In marine environments, nitrogen is typically the limiting nutrient (Howarth and Marino, 2006), so its addition will do likewise. The excess nutrients are released into the environment in two forms, dissolved nutrients and particulate nutrients.

FIGURE 2
Model simulation of phosphorus plume released by fish cages



Source: Legovic, Janekovic and Gecek (2003).

1.1 Dissolved nutrients

Dissolved nutrients from fish farms arise from feed and faeces (Nash, 2001; Pawar, Matsuda and Fujisaki, 2002), fish respiration and metabolites and benthic flux; rereleased nutrients from the sedimented wastes are major sources of dissolved nu-

trients from cage farming (Nash, 2001). Soluble nutrients arising from the digestion processes of farmed individuals will dissolve in the water column, and their dilution and transport is a function of water current dynamics (Figure 2).

Dissolved nutrients are typically dispersed rapidly and utilized by bacteria, phytoplankton and zooplankton. However, if there are high levels of nutrients released on a continuous basis, then this can lead to eutrophication and/or algal blooms. Eutrophication, low oxygen events and fish kills affecting local fisheries and fish-cage production are common events in some lakes and reservoirs in Asia; in these there is a high density of small-scale fish cage farms that together produce excess nutrients in dissolved and particulate form, and therefore exceed the carrying capacity of the waterbody (e.g. in Indonesia, Abery *et al.*, 2005). According to Olsen *et al.* (2006), the most important factors determining the impact of fish farming on water column nutrients, water quality and pelagic ecosystems are:

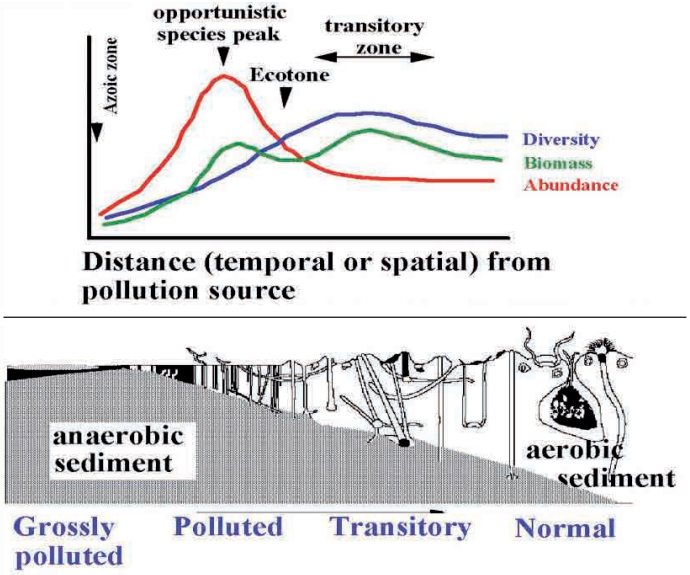
- the loading rate of inorganic nutrients, especially nitrogen for marine systems and phosphorus in freshwaters;
- the local hydrodynamics and depth of the cage sites;
- the degree of exposure of bays and near-shore coastal areas in terms of water refreshment; and
- the stocking density and FCR of fish (local farm scale) and the density of fish farms (waterbody scale).

Of these factors, the most important driver of the impacts of nutrients on water quality in the water column is hydrodynamics. A large farm (or a large number of small farms) located in an enclosed waterbody will have a higher local severity of impact than will the same farm (or farms) when located in a more open or exposed site with stronger hydrodynamic conditions; the latter will have a less severe impact but one which will extend over a larger area. Excess inorganic nitrogen and phosphorus from fish cages are available immediately for phytoplankton uptake. Sites with low flushing will exhibit increased phytoplankton biomass with peak soluble nutrient loadings when feed inputs are highest.

1.2 Sedimented nutrients

Solid waste consisting of uneaten feed pellets, feed fines (fine particulates caused by pellet damage during transport or automatic feeding systems) and faecal material can also accumulate below culture cages and in the outflows of aquaculture facilities. Particulate nutrients settle and are assimilated by sediment benthos flora and fauna. If particulate nutrients are in excess of the assimilation capacity, then they accumulate, altering the biodiversity. In extreme cases they cause anoxic conditions devoid of life in the sediment and the smothering of nearby sea grasses and corals (Figure 3). The accumulation will also depend on local currents and depth. Organic sedi-

FIGURE 3
Gradient of benthic impact from a nutrient source



Source: Pearson and Rosenberg (1978).

ments can also impact benthic (e.g. seagrasses) and sensitive habitats (e.g. corals) close to the farm (Holmer *et al.*, 2008). These areas may be important as a food source or as habitats for local wild fisheries. With high FCR, less of the nutrients are taken up by the fish and more are released into the environment. Improvements in FCR will therefore reduce nutrient impact in the vicinity of the cages. Reduction of feed loss and improvements in nutrient conversion efficiency will reduce (improve) FCR. FCR is also affected by fish size, water temperature and fish status.

In pond culture, much of the excess nutrients are either utilized by primary production or accumulate on the pond bottom. However, nutrients are released into the environment during water exchange and at harvest time when pond water is released to the environment as a point source release. In contrast, in cage and pen culture, water passes through the nets freely and the distribution of the nutrients is highly influenced by the hydrodynamics of the site location.

2. NUTRIENT IMPACTS FROM DIFFERENT CULTURE SYSTEMS

2.1 Prawn and tilapia pond culture

In fish and crustacean pond culture, much of the excess nutrients are either utilized by primary production, or eaten by the fish, or accumulate on the pond bottom as sediments. However, nutrients are released into the environment during water exchange and at harvest time when pond water is released to the environment as a point source release into the river, estuary or sea.

However, poor FCR causes a disproportionate increase in total P and N output loadings. Boyd *et al.* (2008) calculate that total P and N loadings from shrimp farms increase by 27.7 percent and 35.8 percent, respectively, for an increase in FCR from 1.6:1 to 2.0:1 (i.e. 25 percent). This pattern also follows in the case of Nile tilapia reared in ponds, where total P and N loadings increase by 47.0 percent and 36.1 percent, respectively, for an increase in FCR from 1.6:1 to 2.0:1 (25 percent) (Table 1).

TABLE 1

Calculated values of nitrogen (N) and phosphorus (P) loadings from fish and shrimp ponds with increasing feed conversion rate (FCR)

Variable	Black tiger prawn		Nile tilapia	
Change in FCR	1.6:1	2.0:1	1.6:1	2.0:1
Fishmeal in feed (%)	30		8	
Protein in feed (%)	40		30	
Nitrogen in feed (%)	6.4		4.8	
Phosphorus in feed (%)	1.65		1.00	
Protein in animal (%)	19.3		14.0	
Nitrogen in animal (%)	3.09		2.36	
Phosphorus in animal (%)	0.26		0.75	
Protein conversion rate	0.64	0.80	0.48	0.60
N load (kg N/tonne)	71.5	97.1	53.2	72.4
P load (kg P/tonne)	23.8	30.4	8.5	12.5

Source: Boyd (2008).

2.2 Fish cage culture

In cage and pen culture, water passes freely through the nets, and the distribution of the nutrients is highly influenced by the hydrodynamics of the site location. All excess nutrients are released to the environment, increasing the dissolved nutrient concentration in the waterbody and enriching the sediment beneath the cages. If the environment is not able to assimilate these nutrients quickly enough, they will tend to accumulate, causing eutrophication and changes in benthic biodiversity.

3. FACTORS AFFECTING FEED QUALITY

3.1 Dry feeds

The quality of the dry compounded feeds is influenced by the digestibility of the ingredients, the suitability of the formulation to individual cultured species and season, the stability of the pellets in water, the storage and handling of the feed and whether the feed is extruded or pelleted.

3.2 Trash fish/low-value fish

There is a potential impact on the environment from the practice of feeding trash fish or low-value fish. The nutritional value of wet feed (trash fish) is influenced by its quality and storage, and whether the trash fish is fed whole or cut up, as this influences the leaching of nutrients into the environment before consumption. The age (days after capture) and storage conditions of the trash fish influence its bacterial levels and thus the addition of bacteria to the culture water.

4. FEED AND FEEDING FACTORS AFFECTING ENVIRONMENTAL IMPACT

4.1 Feeding strategy

The greatest determinant of the amount of excess nutrients entering the environment is the use of a poor feeding strategy by the farmer that leads to overfeeding. Poor feed quality and poor feeding strategy have major influences on environmental impact. Excess nutrients not utilized by the fish or shrimp are released into the environment and have to be assimilated or else accumulate. Factors affecting poor utilization of feed, resulting in poor FCR, include the quality of the dry feed or trash fish and the feeding strategy. FCR can vary between 1.2:1 for salmon to 2.8:1 (or higher) for milkfish (commercial pellets), depending on feed quality and feeding strategy. The farmer can improve FCR by applying the correct feed amount, feeding duration, frequency and timing.

4.2 Importance of feed quality and feeding efficiency

Feed can account for up to 60 percent of the total production costs in commercial aquaculture. Aquacultural feed management strategies control how farmers feed their fish and thus have a considerable influence upon the economic and environmental sustainability of the enterprises (Cho and Bureau, 1998). Feed management regulates ration size, the spatial and temporal dispersal of feed, feed delivery rate and the frequency and duration of feeding events (Talbot, Corneillie and Korsøen, 1999). In addition to influencing key performance indicators, such as growth rate and FCR, each of these components can also have a profound effect upon the environmental impact of the cultured stock.

A primary concern among aquaculturists is to deliver feeds that meet the nutritional requirements of the fish at ration sizes that optimize both growth and FCR. However, the exact energy and nutritional requirements of numerous fish species (in addition to their appetites and FCR) vary within and between days and also between seasons (Noble *et al.*, 2007). Nutritional imbalances lead to reduced fish performance, whereas underfeeding has detrimental effects on production efficiency (Bureau, Hua and Cho,

2006), and overfeeding typically increases feed wastage (Thorpe and Cho, 1995), which leads to poor FCR (Talbot, Corneillie and Korsøen, 1999) and the wastage of excess feeds, thus contributing to environmental degradation in cage culture (Cho and Bureau, 1998). Commercial fish farmers must address each of these factors when designing economically and environmentally sustainable feed management strategies.

5. FEED FORMULATION AND FISH PERFORMANCE

FCR is determined by the metabolic capacity of fish to digest a given feed and is influenced by diet quality, feeding regime, fish size, seasonal water temperatures and oxygen levels. The recorded FCR for farmed fish vary widely from farm to farm or fish batch to fish batch. The numerous fish-feed producers have responded to the need for simplicity in daily farm operations by producing generic formulations for species such as milkfish. These species are grown under a range of very different culture conditions (e.g. in ponds and cages); the feed manufacturers therefore offer feed products recommended for specific culture systems. The nutritional requirements of the fish remain the same in both systems; however, due to natural production in the ponds, they do not require the same feed formulation as in cages to meet this requirement. It is important to establish both the cost efficiencies and the potential impacts on animal welfare and the environment when formulating species-specific feeds and developing feeding protocols.

The extent to which the nutritional requirements of farmed animals are met determines to a high degree their performance. Unlike mammals, fish may use dietary protein – which is an expensive nutrient in fish feed formulation – as an energy source, in preference to lipids and carbohydrates. Therefore, the determination of optimum dietary levels of protein and energy (i.e. the combination of protein/lipids and carbohydrates in the diet) is a crucial parameter for effective feed formulation. Moreover, as the protein and energy demands of fish constantly change, multiple diets need to be formulated. It is therefore important to determine the optimal stages in fish growth where a feed formulation change can offer maximal gain (Lupatsch and Kissil, 2003). The nutrient composition of fish feeds is a determining factor in fish performance and feed utilization efficiency.

6. FEED MANAGEMENT

One of the greatest causes of excess nutrients entering the environment is overfeeding due to the use of a poor feeding strategy. Farmers can improve FCR by providing the correct feed amount, feeding duration, frequency and timing. Aquacultural feed management strategies control how a farmer feeds his fish. In addition to influencing key performance indicators, such as weight gain and feeding efficiency, each of these components can also have a profound effect upon fish behaviour and welfare. A primary concern among aquaculturists is to deliver a ration size that optimizes both growth and feeding efficiency; many aquaculturists still rely upon experience or feed tables to establish the daily ration sizes for fish. Although these recommended rations are based upon extensive research into fish nutrition, they assume that fish will consume food whenever it is offered, irrespective of time of day or feed regime. However, farmed fish show marked variations in appetite both within and between days (Noble *et al.*, 2007), and farmers need to understand this appetite variability in order to prevent episodes of underfeeding or overfeeding.

Underfeeding reduces feeding efficiency (Bureau, Hua and Cho, 2006) and growth (Gaylord, MacKenzie and Gatlin, 2001), and increases competition (McCarthy, Carter and Houlihan, 1992) and fin damage (Hatlen, Grisdale-Helland and Helland, 2006). Overfeeding also reduces feeding efficiency (Talbot, Corneillie and Korsøen, 1999) and increases feed wastage (Thorpe and Cho, 1995), which in turn can increase environmental impacts and environmental degradation (Cho and Bureau, 1998). Commercial fish farmers must address each of these factors when designing welfare friendly and economically sustainable feed management strategies.

7. CASE STUDY ON MILKFISH CULTURE IN BOLINAO, THE PHILIPPINES

This section describes a case study (White *et al.*, 2007) of the impacts of fish culture in Bolinao, Pangasinan Province, the Philippines due to poor feed quality and feeding strategy. It describes the aquaculture production in the enclosed bay and the environmental impacts that it causes. It also describes the possible methods for mitigation, which include improved feed quality, the prevention of overfeeding and the mixing of fed species with unfed (extractive) species *via* integrated multitrophic culture.

In April 2005 there were 460 fish cages in this location, of which 322 were operational (70 percent) and 138 were nonoperational (30 percent). The total operational fish cages had a volume of 371 910 m^3 and were stocked with milkfish (98 percent) at an average size of 304 g and a stocking density of 15.4 kg/m^3. The standing stock was 3 687 tonnes of fish. The fish were fed at 2.85 percent body weight per day using 103 tonnes of feed per day. The production cycle from stocking of fry to harvest (average market size of 433 g) was 6.8 months, giving 1.76 crops per year per cage. The total production per cycle was 5 025 tonnes, and the total production per year from cage culture was 8 867 tonnes.

There were 266 fish pens, of which 217 (82 percent) were operational and 49 were nonoperational. The total operational fish pens had a volume of 3 046 029 m^3 and were stocked with milkfish. There were 11 356 261 fry stocked at an average of 2 g, which were grown to a market size of 466 g in 4.17 months. The pens held milkfish at an average size of 245 g and a stocking density of 1.04 kg/m^3. The standing stock was 3 305 tonnes of fish. The fish were fed at 3.5 percent per day using 117 tonnes of feed per day. The production cycle from stocking to harvest (average market size of 466 g) was 4.17 months, giving 2.88 crops per year per pen. The total production per cycle was 5 027 tonnes and the total production per year from pen culture was 14 467 tonnes.

There were also 254 oyster farms, of which only one was nonoperational. The total operational oyster farms had 253 000 poles with a total length of 819 000 m of pole.

FIGURE 4
Location of fish and mollusc farming structures in Bolinao, 2004 (fish cages – purple, fish pens – green, fish ponds – yellow, oyster farms – red)

Source: Google map overlaid with fish farm structure locations, adapted by R. Palerud and P. White.

The production per cycle from all the oyster farms was 1 638 tonnes. There was only 1 cycle per year, giving a total production per year from oyster culture of 1 638 tonnes.

In April 2005, there was therefore a total standing stock of 6 992 tonnes of fish, giving an annual production of 23 335 tonnes. During this month, an average of 220 tonnes of fish feed was fed per day. There was also an annual production of 1 638 tonnes of mussels (extractive species). The sea surface area in Bolinao (i.e. not including the islands) is 28 882 032 m² (2 888 ha). Therefore, there was a production of 8.08 tonnes of fish per ha and 0.57 tonnes of mussels. The location of the fish and shellfish structures in the bay in 2004 is shown in Figure 4.

A survey that was undertaken by the EMMA Project team in 2005 and 2006 to establish the impact of the fish production on the environment (White *et al.*, 2007) included the following:

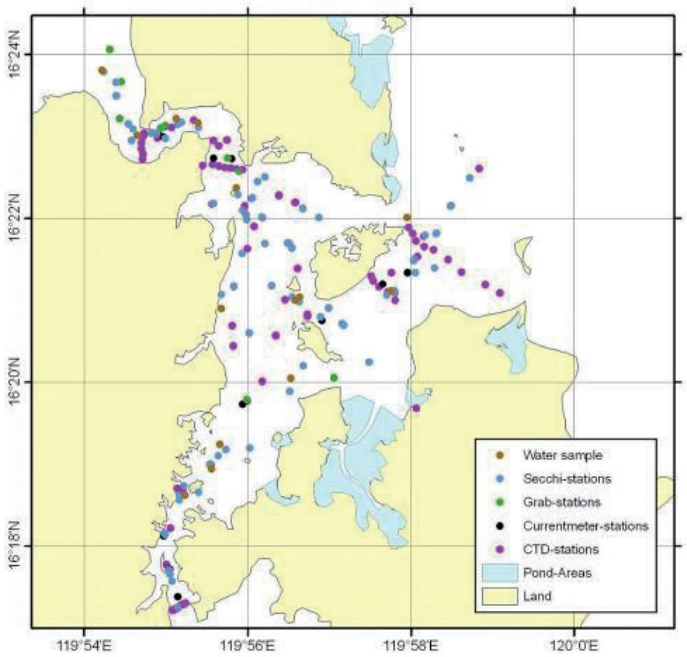
- profiling of water temperature, salinity and oxygen levels;
- determining and analyzing the bathymetry (depth recordings) of the area;
- recording tidal range and current speed, direction and dispersion;
- determining water quality (including chlorophyll, phosphorus, nitrite and ammonia);
- analyzing sediments (biological and chemical); and
- collecting weather data (wind direction, speed, frequency; temperature).

Data were collected from a large number of sampling points within and outside the bay (Figure 5).

Heavy impact on sediments was found in areas with a high density of cages but impacts were less severe in those with fish pens and oyster culture. High levels of chlorophyll and low Secchi depth readings were found in the central areas of the bay, where residence time was the greatest. Poor sediment conditions were found in the channel areas, where the concentration of cages were greatest; however, surprisingly, sediment conditions were relatively good in central parts of the bay and close to areas of oyster culture, leading to the hypothesis that oyster culture was in some way mitigating the environmental impact on sediments (Figure 6).

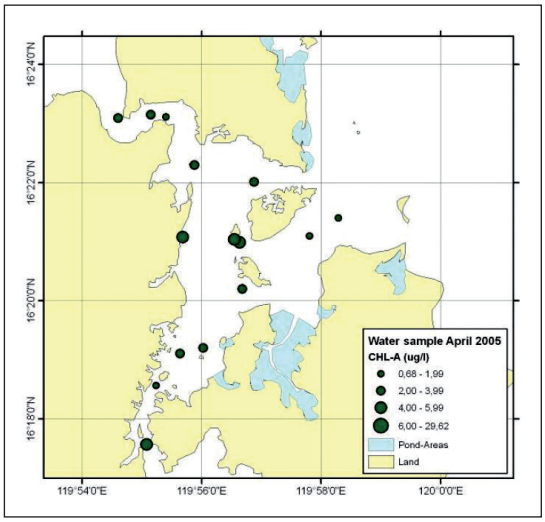
In areas with poor environmental conditions, the sediments had a high organic content and smelled of hydrogen sulphide (H_2S). In these samples, there were no live animals recorded. Stations with bad sediment conditions were often related to areas with high fish farming activity. In areas with a lower density of fish cages, there was no H_2S smell or high organic content, and live benthic fauna was found.

FIGURE 5
Sampling sites in Bolinao

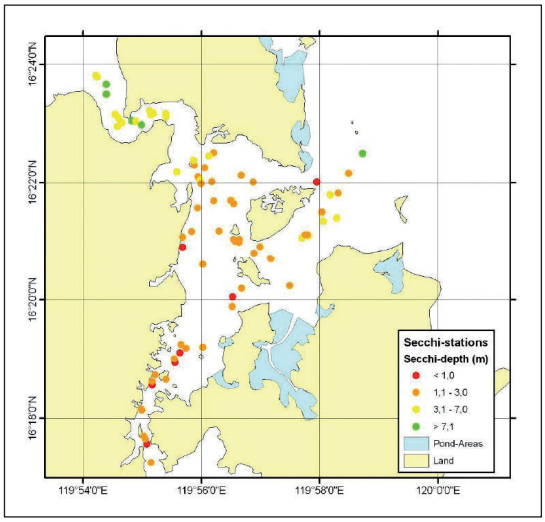


Source: EMMA project results (White *et al.*, 2007).

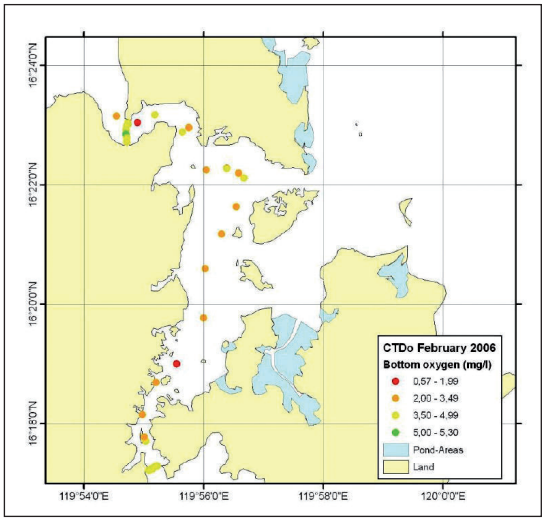
FIGURE 6
Water and sediment quality in Bolinao, 2005 and 2006



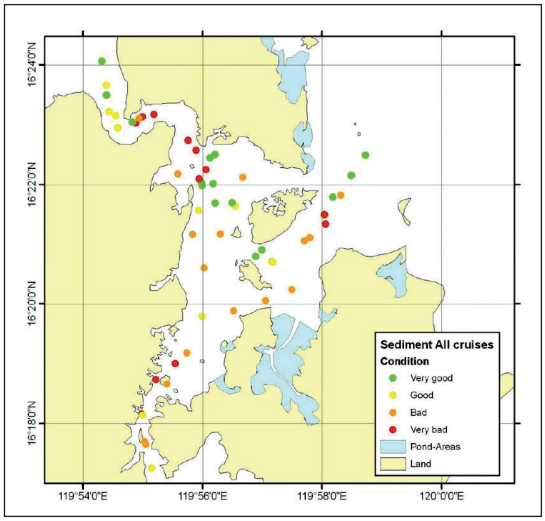
Chlorophyll-*a* measurements



Secchi-disk measurements



Oxygen levels in bottom water



Sediment conditions

Source: EMMA project results (White *et al.*, 2007).

7.1 Modelling carrying capacity

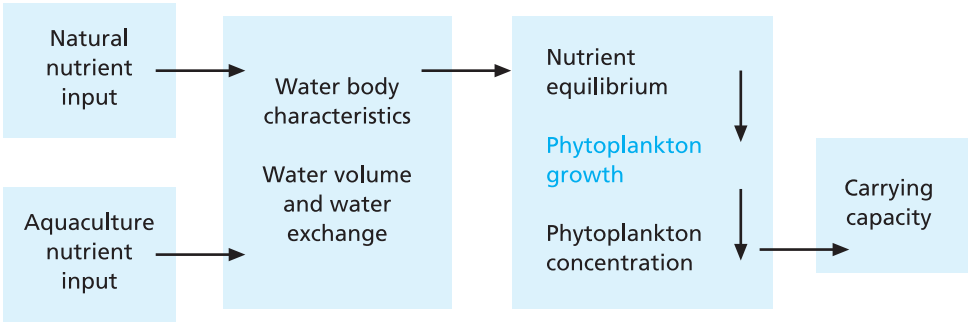
Environmental carrying capacity for fish aquaculture is defined as the maximum number of fish of a given species that may be grown sustainably in the waterbody being considered. This maximum is limited by a variety of factors, such as the water residence time and the quantity of nutrient entering the waterbody. Computation of carrying capacity should be based on the condition which limits the stock maximally. In other words, it must be based on the limiting condition, which in this case is the ability of the environment to assimilate the natural and aquaculture nutrients.

The carrying capacity model that was developed was based on three steps (Figure 7):

- the rate of water exchange with neighbouring water is determined;
- the growth of phytoplankton and the concentration that it is able to attain with given natural external sources is calculated, allowing the calculation of the remaining concentration of phytoplankton that may be reached by increasing aquaculture production; and

- the fish stock is increased (or decreased) theoretically until the critical phytoplankton concentration is reached. The value so obtained will define the carrying capacity of the waterbody for a given species of fish.

FIGURE 7
The process of determining carrying capacity for fish aquaculture based on determining the critical phytoplankton concentration



Fish aquaculture emits nutrients into the waterbody, seen as an increase in the inflow of nutrients. Since the inflow of water does not change, an increase in fish production results in an increase in average nutrient concentration. Increasing nutrient inflow results in an increase in phytoplankton concentration. Therefore, the increase in steady state of phytoplankton concentration is linearly related to the increase in nutrient inflow. The critical phytoplankton concentration is one of the key parameters that define the carrying capacity of aquaculture in a studied area.

Studies (Florida Lakewatch, 2000) have shown that when algal biomass exceeds 100 µg/litre (measured as chlorophyll concentration), there is an increased probability of a fish kill. Fish kills, however, typically only occur after three or four cloudy days. During this time, algae consume oxygen rather than produce it, because they do not have sunlight available to help them photosynthesize more oxygen. This can lead to oxygen depletion. Without oxygen, aquatic organisms, including fish, die.

The carrying capacity modelling calculations (Legović *et al.*, 2008) suggest that aquaculture in Bolinao Bay is close to carrying capacity during average tidal exchange. This means that during periods of low tidal exchange and no wind, carrying capacity is exceeded.

7.2 Possible mitigation strategies

A number of recommendations to mitigate impacts were drawn up by the project (White *et al.*, 2007), including:

- reducing nutrient output by improved FCR through improving feeding strategy and reducing overfeeding;
- reducing nutrient outputs by increasing food quality through improved species-specific formulation of feeds, including ingredients with higher digestibility;
- increasing the stability of pelleted feeds *via* the use of a good binder or the use of extruded feeds;
- using nutrients from fish production by extractive species, such as oysters in marine and brackishwaters and hydroponics in freshwater; and
- zoning aquaculture into areas away from sensitive habitats and within the local carrying capacity.

The last strategy may require the removal or re-siting of some cages from the area, such that cage culture provides the greatest benefits in terms of livelihoods to the largest number of people in the area.

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Economic, regulatory and legal review of feed management practices

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ABSTRACT

An analysis of the legal and regulatory frameworks that have been developed to optimize feed management practices and reduce the negative environmental impacts that add to poor feed management is presented. To date, such frameworks include: (a) establishing minimum feed performance criteria (e.g. feed conversion ratio (FCR), nutrient digestibility); (b) placing restrictions on nutrient composition in formulations (e.g. nitrogen and phosphorus levels); (c) restricting feed use; (d) restricting environmentally unsustainable feeding practices; and (e) promoting better management practices (BMP) and codes of conduct to improve feed management. In many production systems, feed management affects the quality of farm effluent streams; thus regulatory frameworks focusing on the monitoring and control of effluent streams may also indirectly impact on feed management practices. Such regulations include: (a) treatment regulations to treat effluent streams prior to discharge; (b) limiting the quality and or quantity of effluent that can be discharged; (c) limiting farming activities in an area based on effluent carrying capacities/dispersion; and (d) promoting BMP and monitoring protocols to manage effluent streams. The efficacy of introducing these legal and regulatory frameworks to improve feed management practices is discussed.

A financial analysis of feed management practices was undertaken for an intensive land-based recirculating marine finfish farm culturing the Japanese meagre (*Argyrosomus japonicus*), and a comparison was made between the economic efficiency of using semi-intensive and intensive pond culture techniques for Nile tilapia (*Oreochromis niloticus*) culture. A bio-economic model was developed to describe the financial efficiency of the meagre farming operation under variable production scenarios. The model was used to interrogate the effect that feed management practices have on the economic viability of the production system. In addition, a sensitivity analysis was undertaken to establish the effect that feed type, cost, feed conversion and growth have on the economic viability of the farming operation. With respect to tilapia farming, a rate of return ratio analysis under variable feed conversion scenarios suggests that benefit-cost ratios in semi-intensive farming systems are lower than those observed in the intensive farming systems; this indicates that the intensive farming practices are more economically efficient. Thus, while input costs are higher, returns are

greater, and to optimize economic outputs farmers should be encouraged to intensify their farming practices.

1. INTRODUCTION

In recent years, the global growth of the aquaculture industry has resulted in an ever increasing concern about the environmental impacts accruing to the development of the sector. While these impacts have been extensively reviewed (Barg, 1992), the efficient use of aquafeeds is often viewed as one of the major challenges to the development of sustainable production systems. Effluent streams arising from aquafeeds comprise a solid particulate fraction including uneaten and undigested feed and faeces, and a dissolved fraction comprising metabolic by-products, principally ammonia, urea and phosphate (Bergheim and Brinker, 2003). The quality and quantity of the effluent will vary in response to a number of factors, including the culture species, the production system, and the physical and nutritional characteristics of the feed, and, in this regard, much work has been undertaken to determine both the quantitative and qualitative impacts of feed-derived effluent streams in aquaculture (Azevedo *et al.*, 1998; Lemarié *et al.*, 1998).

In 2008, global compound aquafeed production was estimated at 29.2 million tonnes (Tacon, Hasan and Metian, 2011). As the sector grows, this figure is projected to rise to 71.1 million tonnes by 2020 (Tacon, Hasan and Metian, 2011). The projected expansion of the aquaculture sector and the concomitant increase in the use of compound aquafeeds suggests that all aspects of aquafeed production and feed management will become increasingly important in the future, in terms of limiting the overall environmental impact of the sector.

Traditionally, government agencies provide the legal, policy and regulatory frameworks under which aquaculture and aquafeed use is controlled. In recent years, the emergence of certification bodies, such as the World Wildlife Fund (WWF) aquaculture dialogues, the Aquaculture Certification Council and the Global Aquaculture Alliance (GAA), has seen a new approach to environmental governance. In many respects these ‹non-state, market driven› systems (Vandergeest, 2007) now compete with traditional governmental regulators, in what some authors have termed ‹the privatization of governance’ (Gereffi, Garcia-Johnson and Sasser, 2001). While governments retain the legal mandate to regulate the industry, increasingly, these certification bodies are setting the environmental agenda in terms of influencing the behaviour of farmers and placing limitations on the environmental impacts of their activities.

Notwithstanding the role of the various regulatory bodies, this paper focuses on two themes relating to the use of on-farm feeds and feed management systems. The first theme addresses governance, and outlines the regulatory and legal instruments that are available to control aquafeed use and minimize their impact on the environment; the second theme addresses the economic efficiency of selected farm feed management practices, and provides an economic assessment of the impact that feed management practices have on the economic efficiency of farming operations.

2. A REGULATORY AND LEGAL REVIEW OF FARM FEED MANAGEMENT PRACTICES

The development of legal, policy and regulatory instruments that can be used to control aquafeed use and the environmental impacts that add to their use can be broadly divided into two categories. The first category, best described as the ‘direct approach (or practice-based governance)’, comprises instruments that focus on aquafeeds *per se* and regulate farmers in terms of the feeds and the associated feed management practices that they can apply in their farms. Examples in this category include the establishment of feed performance criteria, the regulation of feed management practices and feed formulations, and the restriction of feed use through the introduction of feed quotas. The

second category, best described as the 'indirect approach (or result-based governance)' addresses feed management through the regulation and control of the impacts that add to the farming activities; while these instruments do not regulate aquafeed use *per se*, when viewed holistically their introduction encourages farmers to optimize feed use and minimize the environmental impact of their use. Examples in this category include the establishment of regulations to treat effluent streams, temporal and spatial discharge limitations, and the establishment of discharge limitations according to the carrying capacity of a waterbody. It should be noted that while the 'direct approach' targets feed use *per se*, and the 'indirect approach' targets the outcomes of feed use, they are both based in the application of regulatory frameworks, system performance criteria and the introduction of better management practices (BMP). In the following sub-sections, we provide a brief summary of the pros and cons of each approach.

2.1 The Direct Approach

2.1.1 Feed performance criteria

Proscribing minimum feed performance criteria and thereby ensuring the quality of aquafeeds that are used can provide an effective way to mitigate some of the environmental impacts of their use. Feed performance criteria that can be applied typically include limitations to feed conversion ratios (FCR), nutrient digestibility and retention, and the physical characteristics of the feed, such as the percentage of fines in the feed. In a review of aquaculture legislation across the European Union (EU), Tacon and Forster (2003) noted that Denmark was the only country that used feed performance criteria as a component of their aquaculture regulatory systems. Indeed, Danish farmers must demonstrate that their FCR do not exceed 1.2:1 – 1.5:1 (depending on the culture system), that the aquafeed feed has a minimum digestibility of 70 percent and that the fines in the feed are less than 1 percent of the total feed (Pedersen, 2000).

The use of performance criteria such as FCR, fish-in fish-out ratios (FIFO), or forage fish equivalence ratios (FFER), forage fish dependency ratios (FFDR) and fish protein indices (FPI) as indicators of on-farm feed efficiency is becoming increasingly popular with some of the certification bodies. In its certification criteria for tilapia, catfish, shrimp, and 'Pangasius catfish' (www.gaalliance.org/bap/standards.php), the GAA recognizes the use of FCR and FIFO as a monitoring tool. However, as opposed to proscribing absolute levels for these indicators, the GAA proposes using them as guides to monitor feed efficiency. In contrast, the WWF certification programmes (www.worldwildlife.org/what/globalmarkets/aquaculture/aquaculturedialogues.html) propose applying absolute levels to these types of performance ratios in their certification criteria. While FCR provides the most simplistic indication of the feed efficiency, FFER/FFDR provide more complex indicators that give information pertaining to the use of dietary fishmeal and fish oil during the culture process, and thus a means of monitoring and ultimately limiting the level of fishmeal and fish oil used in aquafeeds. The monitoring and assessment criteria that the WWF applies are species-specific. For example, the draft salmon dialogues (WWF, 2010a) propose FFDR values for fishmeal and fish oil of <1.31 and <2.85, respectively. The salmon dialogues focus on FFDR values, as the industry has historically been reliant on forage fish as the primary dietary protein source. Thus inclusion of this criterion is an attempt to reduce the levels of forage fish in dietary formulations and, in doing so, reduce fishing pressure on the associated capture fisheries. In contrast, the *Pangasius* standards (WWF, 2010b) prefer to use economic food conversion ratio (eFCR) and FFER to monitor feed efficiency (eFCR <1.75:1 per production cycle; FFER must not exceed 0.5). The adoption of FFER in the *Pangasius* dialogues recognizes the need of the sector need to reduce its reliance and impact on forage fish fisheries. In this regard, the use of forage fish or trash fish as a sole feed source is also prohibited by the dialogues. Finally, the

draft trout standards (WWF, 2010c) prefer to use both eFCR (eFCR <1:1 up to 500 g; <1.2:1 between 500 g and 4 kg) and protein digestibility (≥85 percent), and further specify that dietary nitrogen and phosphorus retention should be a minimum of 40 and 45 percent, respectively. The WWF (2010a) also advocates the use of fines in the feed as a measure to reduce feed losses to the environment. In this regard, the proposed salmon standards require that less than 1 percent of the feed comprises fines.

The use of feed performance criteria represents a useful regulatory tool in those instances in which commercially produced dry compound aquafeeds are being used to provide the complete nutritional requirements of the fish. Under such circumstances, it is relatively easy to calculate feed performance criteria with accuracy. However, their use becomes problematical when moist farm-made aquafeeds are used, as it becomes difficult to determine feed composition and ingestion rates accurately. The use of these criteria is problematic in semi-extensive and extensive culture systems where the fish derive feed from both compound aquafeeds and the natural productivity of the systems. In such cases, it is difficult to assess accurately the relative nutritional impact of the compound aquafeeds and the feed derived from the natural productivity in the system. Nevertheless, poor feed performance criteria in these systems can be used as an indication that the farming practices are suboptimal. The application of feed performance criteria is therefore both species and systems dependent.

2.1.2 Feed practices – regulating feed type

Regulating the types of feed that can be used and encouraging farmers to adopt sustainable feed management practices can improve feed efficiency and the overall environmental sustainability of the farming operations. For example, in tank-based production systems, Warrer-Hansen (1982a,b) reported values of food wastage as 1–5 percent, 5–10 percent and 10–30 percent, respectively, for dry diets, moist diets and wet diets, a situation that is likely to be compounded in cage culture systems (Islam, 2005). The use of wet diets and, most notably, trash fish is particularly problematic and can lead to environmental problems such as nutrient enrichment (Gao *et al.*, 2005) and disease transfer (Kim *et al.*, 2007). For reasons related to nutrient loading and energy loss, the practice of feeding trash fish has been banned in some countries, such as Denmark (Pedersen, 2000), but remains permitted in others such as China, Indonesia Thailand, Viet Nam (Hasan and Halwart, 2009; Hasan, 2012). The WWF (2010b) *Pangasius* certification standards ban the direct use of fish and fish products (trash fish) on the grounds of poor environmental sustainability and negative impacts to fish biodiversity. Nevertheless, there are likely to be some artisanal activities – such as the nascent crab fattening industry in Tanzania and Kenya– where the quantities of trash fish required are minimal, and thus the potential negative impact of their use should also be minimal. Furthermore, there are also countries (e.g. Viet Nam and Japan) where many finfish mariculture operations are almost totally dependent on trash fish as feed for the cultured carnivorous fish (De Silva and Hasan, 2007; De Silva and Turchini, 2009). In such cases, a simple ban would be difficult to impose and negatively affect production; it would therefore be expedient to investigate alternatives to the use of wet feeds and trash-fish feeds, and encourage farmers to start to use moist and dry feeds.

2.1.3 Feed formulations

Regulating feed formulations or setting levels of specific nutrient inclusion rates in them provides a mechanism that could potentially be used to maximize nutrient uptake and limit effluent streams. This approach to regulating feed is seldom applied; for example, Tacon and Forster (2003) established that only Denmark amongst the EU countries reviewed had implemented regulations to limit nutrient inclusion rates in aquafeeds. Under the Danish regulations for polluting industries (Ministry of the Environment, 1990), the energy content of compound feeds may not exceed 5.6 Mcal/kg and the

dry matter inclusion rates of nitrogen and phosphorus must not exceed 8 percent and 0.9 percent, respectively (Pedersen, 2000). There are two major drawbacks to this approach to feed management. Firstly, the nutritional requirements vary according to a number of factors that include species, animal size, health and nutritional status, culture conditions and environmental parameters. Variations in these parameters mean that the nutritional requirements are not static across all production systems. Setting a rigid set of nutritional parameters to which feeds must comply will almost inevitably result in inefficiencies in feed utilization, as feed manufacturers may not be able to optimize feed formulations in terms of nutrient utilization and growth. A second factor that needs to be considered is that formulation technologies are changing rapidly, and it is difficult for regulators to respond readily to these changes. For example, the addition of microbial phytase in aquafeeds to increase the digestibility of phytate-bound phosphorus in plant protein sources has the potential to increase the bioavailability of these phosphorus sources and reduce the phosphorus levels in effluent streams (Cao *et al.*, 2007). These types of technical advances have the potential to make nutrient inclusion regulations redundant, as the technical rationale for setting specific inclusion rates for a specific nutrient will inevitably change.

2.1.4 Time-based feed use restrictions/quotas

Historically, applying feed quotas and regulating the amount of feeds a farm can use over a given period of time has proved an effective tool with which to control production and emissions. Feed quotas are usually calculated by multiplying a prescribed FCR value to produce an annual feed quota that is commensurate with the production volume allocated to a farm. The FCR applied may vary according to the production system employed and the anticipated FCR that can be achieved. For example, in Denmark, feed quotas that are allocated to cage culture sites apply an FCR of 1.5:1, while their land-based counterparts have to apply an FCR of 1.2:1 (Pedersen, 2000).

Both Norway and Denmark have applied feed quota legislation, and in this regard, it is instructive to review the impact that this legislation has had on sectoral growth. In 1996, the Norwegian Government introduced feed quotas in a response to accusations by the EU of dumping under-priced Norwegian salmon into the EU markets. In addition, a salmon trade agreement increasing export tariffs to the EU was introduced. At the time, feed quotas were viewed as a mechanism with which to limit production and regulate the market (Aarset and Jakobsen, 2009). Apparently, the quota system was effective in limiting production; prior to the introduction of the quota system (1992 to 1997), production in the industry increased nearly threefold. On adoption of the quota system in 1996, the growth of the sector between 1999 and 2002 was restricted to a mere 13 percent. While other factors, such as the increased export tariffs to the EU, may have played a role in reducing sectoral growth, the feed quota system is likely to have also played an important role in restricting growth (Aarset *et al.*, 2005; Aarset and Jakobsen, 2009). In 2004, the quota system was removed, and although the sector remains tightly regulated in terms of emissions, feed use *per se* is no longer restricted.

A principal concern with the use of quotas is that while they successfully limit emissions and the negative environmental impacts that may accumulate to feed use, they also restrict the ability of the farmer to increase production, and hence negatively impact sectoral growth. As production is limited by feed availability, the quotas will incentivize farmers to maximize feed use; while increasing feed efficiencies will probably result in reduced emissions, quotas will fail to incentivize farmers in terms of investing in emission reduction technologies that reduce the environmental impact of their activities. This being the case, placing quotas on the amount of feed that can be used primarily becomes a vehicle with which to constrain production, and their use would probably have a minimal effect on promoting environmental sustainability.

Arguably, a more effective way to regulate the industry would be to remove the feed quotas and instead focus on regulating emissions. Under this scenario, farmers would be motivated to increase both production and investment into emission reduction technologies; this would enable them to increase production while remaining within their emissions targets. In this regard, the current regulatory frameworks that are used in Denmark are viewed as limiting the development of the sector (Jorgensen, Hojgaard and Jepsen, 2005), and thus Denmark is currently in the process of reviewing the regulatory systems and changing the focus from feed quotas to emissions targeting.

2.2 The Indirect Approach

2.2.1 Regulations to treat effluent streams

Regulations to treat effluent streams prior to discharge can be used to control the potential negative impacts associated with aquafeed use. Typically, such regulations would make it mandatory to install wastewater filtration systems based on mechanical filtration (e.g. settlement ponds, drum filters) and biofiltration technologies. Generally, regulations to treat effluent streams are either enforced at the sector level, encompassing all producers, or on a discretionary basis relating to individual farms and depending upon a specific need to protect a given waterbody.

With respect to imposing effluent stream regulations at the sector level, an example is evident in Germany, where all farms that use pond-based culture systems are required to pass their pond cleaning effluent water through a sedimentation system prior to discharge (Bergheim and Brinker, 2003). In Greece, regulators recommend wastewater treatment options for land-based farms (Papoutsoglou, 2000), and some of the prawn-producing countries, such as Australia (Donovan, 1997) and Thailand (Tabthipwon, 2008), have developed BMP/codes of practice and legislation that require effluents containing suspended solids over a certain concentration to be passed through settlement ponds prior to discharge.

An example of the controlling of effluents at the farm level is the United Kingdom, where fish farms are required to apply for a discharge licence. The quality of the discharge water is subject to an environmental quality standard (EQS[1]) and, for a given waterbody, an environmental quality objective (EQO) is set. The licence conditions reflect these standards and objectives in terms of designating water quality parameters such as levels of biological oxygen demand (BOD), dissolved oxygen (DO) and ammonia in the effluent stream. In terms of conforming to the licence conditions, regulators may specify the use of water treatment systems to ensure that the water quality parameters are met (Bergheim and Brinker, 2003). It should be noted that specifying water treatment systems is only one of the regulatory options that are available to the regulators; thus not all farms will be required to install treatment systems.

Regulations to treat effluent stream have limitations in that they are only suitable for land-based operations such as tank, raceway and pond culture systems, where effluent streams are easily defined, monitored and regulated. They are not suited to open-water culture systems such as cage culture operations, where waste products are immediately released and assimilated into the wider environment.

2.2.2 Limiting the concentration of nutrients in discharge waters

Limiting the concentration of nutrients in discharge waters is a common mechanism with which to regulate the impacts of farming activities and, indirectly, aquafeed use. Depending on the regulatory framework in place, limitations normally focus on total nitrogen and phosphorus emissions, the levels of suspended solids, regulating the BOD of the effluent and ensuring minimum DO and ammonia concentrations. Among

[1] Regulated by the Department of Environment, Food and Rural Affairs (www.defra.gov.uk) and the Scottish Environment Protection Agency (www.sepa.org.uk).

others, these types of regulations are used widely across Europe (EC, 1995; OSPAR, 2000), in Canada (Anon. 1994), some states in the United States of America, Australia (Anon, 2000) and Thailand (Tabthipwon, 2008). In addition to government regulations, certification agencies such as the WWF use effluent streams as indicators with which to measure the environmental sustainability of farming operations (WWF, 2010c).

While limiting the concentration of nutrients in effluent streams will encourage farmers to improve their utilization of aquafeeds and invest in wastewater treatment systems, it also requires structured monitoring protocols and programmes, and regulatory authorities to provide compliance services. The costs associated with setting up the water quality monitoring programmes usually accrue to the farmers. For small-scale producers that have limited resources – both financially and technically – the implementation of these types of monitoring programme are likely to prove problematical. Furthermore, such systems require government agencies to develop and invest in compliance mechanisms. While many governments in the developed world could in all likelihood afford to undertake these types of interventions, other countries with limited financial and technical resources may find them difficult to implement.

2.2.3 Limiting effluent discharges per production volume or over time

In many respects, limiting effluent discharges over time or per production volume represents a similar regulatory mechanism to placing limitations on the concentration of nutrients in discharge waters. The principle difference is that the former has a temporal/production component, in that farmers are provided with discharge limits that they are not allowed to exceed in a given period of time or production volume, and the latter provides discharge limits that must be adhered to at all times. All these regulatory mechanisms require some form of verification through compliance monitoring. However, those regulations that are define limits to discharges based on production volumes, or production volumes over time, can be assessed using simple mass balance equations and a minimal physical monitoring of effluents or production system efficiencies. For example, the WWF trout aquaculture dialogues (WWF, 2010c) propose limiting the amount of total nitrogen and phosphorus discharged per tonne of production. The amount of nitrogen and phosphorus produced per tonne of trout is based on the amount of nitrogen and phosphorus content of the feed that is used, how much is removed by the filtration systems of the farms, and the production and retention rates. In terms of monitoring discharges, the only monitoring that is required is to estimate the efficacy of any filtration and disposal systems that are used. All other components of the monitoring process can be accessed from the farm records and the feed suppliers. Thus, in terms of compliance, regulating effluent discharges over time or production volume may prove easier and more cost effective for famers to implement than systems based on the continuous monitoring of effluent streams.

In addition, limiting discharges per production volume is also a useful tool to regulate discharges in open-water production systems such a cage farms, where effluents are discharged directly into the environment. Monitoring effluent discharges in these types of system is technically difficult; thus applying a discharge limit per tonne of production that can be calculated using mass balance techniques provides a simple and verifiable method to control discharges. In this regard, the United Kingdom has adopted a coastal nitrogen waste limit for fish culture of 123 kg of nitrogen per tonne of fish produced (Islam, 2005).

Concomitant with other regulatory measures, limiting effluent discharges per production volume or over time is often used by regulators as one of a number of regulatory options that are available. Among others, these regulations have been adopted by Norway (Bergheim and Brinker, 2003), Denmark (Pedersen, 2000), Finland (Varjopuro *et al.*, 2000) and the United Kingdom (Islam, 2005).

2.2.4 Spatial limitations: licences based on the carrying capacity of a waterbody

The 'assimilative capacity' of a waterbody is defined as the ability of an area to maintain a 'healthy environment' and 'accommodate' wastes (GESAMP, 1986). Licensing aquaculture operations based on the 'assimilative' or 'carrying' capacity of a given waterbody provides regulators with a mechanism with which to set discharge consents, limit the number of farms/production volume in a given area, and motivate farmers to effectively manage their feed use and management practices. A considerable amount of research has been carried out to model the assimilative capacities of coastal (Islam, 2005; Geĉek and Legović, 2010) and inland waterbodies (Dillon and Rigler, 1974a,b; Vollenweider, 1975; Hakanson, Carlsson and Johansson, 1998; OECD, 1982; Beveridge, 1984; Hamblin and Gale, 2002; Johansson and Nordvarg, 2002).

The modelling-based approach was first articulated by Beveridge (1984) and is based on mass balances, nutrient loadings and nutrient-algal models. It is generally recognized that due to the slow water exchange rates in freshwater systems, lakes and reservoirs are usually more sensitive to point source emissions than marine locations (Persson, Håkanson and Pilesjö, 1994). In freshwater systems, this modelling approach is deemed to work well by some authors (Davies, 2000), and less well by others (Yan, 2005). It is important to note that these models only account for water quality dynamics in the water column, depending on nutrient-chlorophyll relationships to predict algal biomass in the water column, and that they do not model biological transfer of nutrients, sediment dynamics or sediment-water interactions (Kelly, 1995; Hakanson, Carlsson and Johansson, 1998). Yan (2005) reviewed the status of these models and concluded that there are important scientific uncertainties about the applicability of conventional mass balance models to cage fish culture. In some lakes, the classical models appear to work but in other cases they have significantly overestimated the impacts of cage operations on lake water total phosphorus levels and concomitant algal levels.

In marine environments, models capable of reflecting nutrient dynamics, primary and secondary production, organic matter decomposition and oxygen dynamics are used in conjunction with hydrodynamic models that predict water flow. Variations in the hydrodynamics of an area (e.g. bathymetry and morphological characteristics) suggest that while these types of model are site specific, the combination of hydrodynamic and nutrient flow models provides an efficient tool to determine the carrying capacity of an area (Geĉek and Legović, 2010).

These types of assessments are increasingly being applied to set carrying capacities. For example, the WWF trout aquaculture dialogue (WWF, 2010c) requires cage farmers to adhere to production levels that are based on the respective carrying capacity of a waterbody.

With respect to the future of these types of intervention, it is probable that as the models are developed further and become more accurate, they will become increasingly important in regulating aquaculture developments. However, the current models, and particularly those that are applied to coastal environments, require significant amounts of data that can be time consuming, technically difficult and costly to collect and collate. Furthermore, there can be significant variations in the carrying capacities as calculated by the various models that are currently available. Thus for the analysis to provide meaningful results, the choice and application of a given model has to be carefully considered, and must be made on the quality of the available data.

2.2.5 Codes of conduct and better management practices

Codes of conduct and best or better management practices (BMP) are increasingly being developed to complement legal and regulatory frameworks. Such codes are self-regulatory, and typically provide guidance on specific operational procedures that are designed to ensure that the industry remains environmentally responsible and

accountable. These codes can be applied at international, regional or national industry association and farmer levels. At the international level, Article 9 of the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) provides the overarching principles required to develop a sustainable industry. Likewise, at a regional level in Europe, the Federation of European Aquaculture Producers (FEAP) has developed voluntary codes of practice that broadly address feed management issues within the EU (Hough, 2001). At the national and farmer association levels, many countries and industry bodies have developed specific codes of conduct and BMP that, among other issues, specifically target feed management. Examples include South Africa (multispecies: Hinrichsen, 2007), Australia (prawns: Donovan, 1997; DPIF, 2006), and Hawaii (multispecies: Howerton, 2001). In addition, specific BMP focusing on feed management (Davis, 2001) and feed manufacturing (FAO, 2001) issues have been developed.

While the majority of BMP represent voluntary codes, in some cases there may be legal requirements for their implementation. For example, in the United States of America, the effluent limitation guidelines for concentrated aquatic animal production systems (CAAP) that are used by state permitting authorities to regulate the sector are based on management practices and record keeping as opposed to numerical discharge limits – although discharge limits may also be applied (EPA, 2006). In terms of developing BMP, facility operators are legally required to design BMP to include practices such as feed management, feed monitoring, solids control and material storage.

3. ECONOMIC ASSESSMENT OF FEED MANAGEMENT PRACTICES

As feed represents one of the highest operating costs in aquaculture systems (Davis, 1990), feed choice and feed management practices are likely to have a significant impact on economic performance. To establish the scale of these impacts, a bio-economic model of an intensive recirculating fish farm culturing the Japanese meagre (or dusky kob) (*Argylosomus japonicus*) was used to assess the impact that these parameters have on the economic viability of the farming operation. The bio-economic model was based on a mass balance analysis, the biological performance indices (e.g. growth, mortality, FCR), environmental tolerances and the optimal conditions for growth of the species. This information was integrated with the infrastructure requirements (e.g. tanks, biofiltration units) and infrastructure costs. The model had 57 variables, including financial modifiers, biotic production variables and abiotic production variables, which could be changed to predict the effects on the income and expenditure, cash flow schedules, internal rate of return, return on equity, and break even production. For the purpose of the analysis, a 600 tonne per year facility producing 750 g fish at a stocking density of 45 kg/m^3 was modelled. Average growth rates over the production cycle were projected at 2.8 g/day, survival was projected at 85 percent, and a base FCR of 1:1 using a feed containing 42 percent protein was applied. With respect to water quality and the level of biofiltration that was required to operate the system, biofilter efficiency was estimated at 65 percent, and nitrate levels in the system were set so as not to exceed 40 mg/l. A water replacement rate of 10 percent of system volume per day was applied.

For the purpose of the analysis, four production scenarios were considered:

1. A base scenario in which FCR increases from 1:1 to 1.6:1 – this scenario was used to provide an indication of the effect that a general deterioration in on-farm feed management has on economic viability of the operation.
2. Optimal production parameters – this scenario was used to demonstrate the effect that operating the system under suboptimal culture conditions, in this case temperature, had on feed use and the economic viability of the operation.
3. Feed formulation – this scenario was used to demonstrate the effect that feed formulation in terms of protein and energy levels has on feed use and the economic viability of the operation.

4. Feed management – this scenario was used to demonstrate the effect that feeding frequency and feeding intensity had on the economic viability of the operation.

Finally, a fifth production scenario comparing the effect of feed management on the economic efficiency of an intensive tilapia culture system using either pressed or extruded feeds, and a semi-intensive system based on the use of fertilizers and pressed feeds was undertaken. This scenario is based on different production and economic models to those used in scenarios 1 to 4.

3.1 Scenario 1 – base scenario

A deterioration in on-farm feed management resulting in poor feed utilization will manifest itself as a deterioration (increase) in FCR. The impact of an increase in FCR on the economics of the operation is presented in Table 1. Assuming that an annual production volume of 600 tonnes is maintained, an increase in FCR from 1:1 to 1.6:1 results in an increase in feed use from 600 tonnes per year to 960 tonnes per year. At a feed cost of US$1.35/kg, this equates to an increase in feed costs of US$490 446, increasing feed costs as a percentage of total production costs from 36.2 percent to 46.1 percent. In addition to the increase in feed costs, the decrease in feed efficiency will result in increased waste products – principally ammonia-N and uneaten feed and faeces – that will need to be removed from the system. The bio-economic model characterizes these waste products as ammonia-N, and assuming that water turnover rates remain constant, the removal of this excess ammonia-N will require the installation of additional biofiltration capacity. An increase in FCR from 1:1 to 1.6:1 requires a 53 percent increase in biofiltration capacity, raising the farm capital expenditure costs (CAPEX) by 4 percent. In addition to the increased CAPEX costs, a 23.9 percent increase in the annual operational costs is required to service the increased feed requirement and operate the additional biofiltration systems. The increase in CAPEX and operational costs associated with an increase in FCR to 1.6:1 results in an increase in the total investment requirement to develop the farm of 15.7 percent. In terms of the economic indicators, the increase in FCR results in a decrease in the net operating cash flow over ten years of 35.5 percent, and a reduction in the internal rates of return (IIR) from 35.3 percent to 15.2 percent. Assuming that investors require IIRs of approximately 30 percent, the model suggests that a deterioration in feed efficiency resulting in an FCR of above 1.3:1 (the IIR at an FCR of 1.3:1 is calculated at 25.5 percent) would make it difficult to access finance for this type of farm.

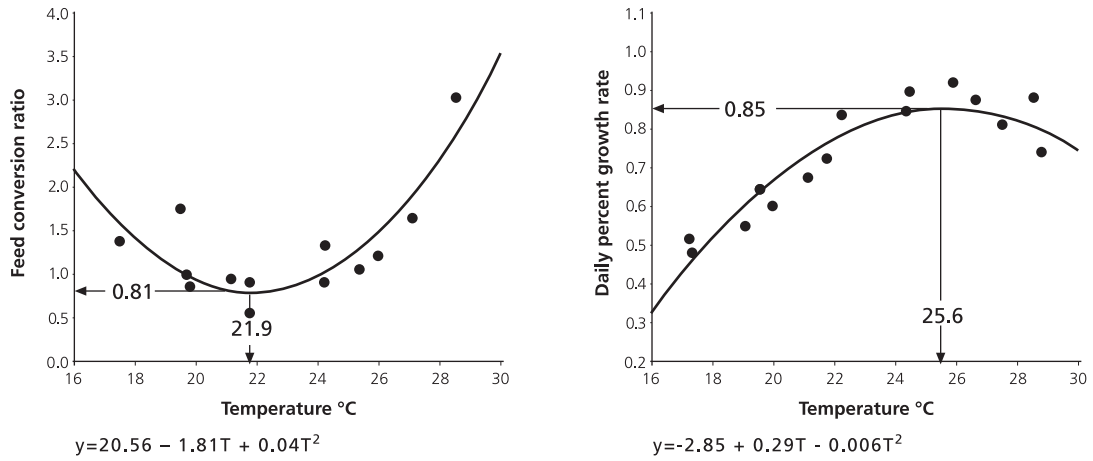
TABLE 1
The effect of variable feed conversion ratio (FCR) on the economic performance of a 600 tonne per year recirculating Japanese meagre farm

Indicator	FCR						
	1:1	1.1:1	1.2:1	1.3:1	1.4:1	1.5:1	1.6:1
Feed (tonnes per year)	600	660	720	780	840	900	960
Cost (US$)	817 410	899 151	980 892	1062 633	1 144 374	1 226 115	1 307 856
Cost increase (US$)	–	81 741	163 482	245 223	326 964	408 705	490 446
Cost of feed (% of production)	36.2	38.1	39.8	41.8	43.2	44.5	46.1
Infrastructure requirements							
Biofilters	19	20	22	24	26	27	29
Blowers	8	9	10	10	11	12	12
Operating requirements							
Electrical requirements (kW/hour)	400	435	470	490	512	547	547
Water requirement	72	79	86	93	100	107	114
Financial indicators							
CAPEX (US$)	1 476 949	1 487 305	1 498 618	1 500 811	1 524 111	1 534 480	1 536 672
(% increase)	–	0.7	1.5	1.6	3.2	3.9	4.0
Working capital	2 106 141	2 195 752	2 285 484	2 355 505	2 450 356	2 539 968	2 609 989
(% increase)	–	4.3	8.5	11.8	16.3	20.6	23.9
Total capital required (US$)	3 583 090	3 683 057	3 784 102	3 856 317	3 974 467	4 074 447	4 146 661
(% increase)	–	2.8	5.6	7.6	10.9	13.7	15.7
Net operating cash flow (10 years)	2 107 929	1 976 131	1 844 264	1 736 010	1 599 956	1 468 158	1 359 904
Reduction (US$)		131 798	263 664	371 919	507 973	639 771	748 025
Internal rate of return (IRR) (%)	35.3	31.8	28.3	25.5	21.7	18.1	15.2

3.2 Scenario 2 – Optimal production parameters

In order to maximize the economic efficiency of a production system, it is necessary to ensure that the system is operated under conditions that optimize production efficiencies; in this regard there are often trade-offs between production parameters. For example, growth is generally maximized at a higher temperature than feed conversion efficiencies (Jobling, 1996; Deacon 1997; Van Ham *et al.*, 2003). Under intensive tank culture conditions, Collete (2007) demonstrated that this was indeed the case with juvenile *A. japonicus*, and it was established that while FCR were maximized at 21.9 °C, growth was maximized at 25.6 °C (Figure 1). Using this as an example, the trade-off between maximizing production efficiencies in terms of maximizing growth or FCR needs to be established, and this can best be undertaken by establishing the economic efficiency of operating the system under different temperature regimes (Table 2).

FIGURE 1
The effect of temperature on feed conversion ratios and growth



Source: Collete (2007).

TABLE 2
The effect of temperature on feed conversion ratio (FCR), growth and economic efficiency of a 600 tonne per year farm

	Temperature (°C)			
	17	**21.7**	**25.4**	**28**
FCR	1.36:1	0.97:1	1.3:1	1.98:1
Growth (g/day)	1.76	2.53	2.94	2.57
Feed requirement (tonnes/year)	892	591	820	1 226
Cost of feed (% operational costs)	42.0	35.2	42.1	50.3
Residency (months)	15	10	9	10
Total capital (US$)	3 927 509	3 554 914	4 003 967	4 498 525
Total capital (% of optimal scenario)	+10.5	0.0	+12.6	+26.5
Internal rate of return (IIR) (%)	16.4	33.0	26.4	0.6

According to Collete (2007), operating the production system at the optimal temperature to maximize feed conversion (21.7 °C) results in an FCR of 0.97:1 and a corresponding growth rate of 2.53 g/day. At the optimal temperature for growth (25.4 °C), FCR is reduced to 1.3:1 and growth increases to 2.94 g/day. With respect to the

operational efficiencies that add to operating the system at these temperatures, the increased growth rate at the higher temperature results in a shortening of the grow-out cycle of one month. However, the poorer FCR at this temperature increases the annual feed requirements from 591 tonnes (at 21.7 ºC) to 820 tonnes (at 25.4 ºC), increasing the proportion of feed costs (as a percentage of operational costs) from 35.2 percent to 42.1 percent. The cost savings that accumulate to operating the system to maximize the growth rate are not offset by the higher feed costs. Indeed, simply operating the system to maximize the growth rate as opposed to maximizing the feed conversion results in a 12.6 percent increase in capital requirements and a concomitant reduction in the IIR from 33 percent to 26.4 percent. Thus, under this production scenario, economic efficiencies are greatest at 21.7 ºC as opposed to 25.4 ºC, and thus farmers should choose to optimize feed conversion over growth rates. At a practical level, market demand issues may require farmers to supply product into the markets at certain times; at these times farmers may choose to maximise growth rates and sacrifice economic efficiencies.

3.3 Scenario 3 – Feed formulation

Feed formulation and the development of cost-effective feeds that optimize growth rates, feed conversion and feed costs are important considerations in optimizing economic efficiencies. Protein traditionally represents the most expensive dietary component in fish feeds. Furthermore, it plays an important role in growth and feed efficiency, and thus can potentially provide a good example of how subtle changes to feed formulations can impact the economic viability of a farming operation. The utilization of dietary protein is related to protein quality, inclusion levels and availability of non-protein energy sources. By optimizing the dietary protein:energy (P:E) levels, protein retention can be maximized, the deamination of amino acids minimized (Lee, Jeon and Lee, 2002), and growth rates and feed conversion efficiencies maximized.

By manipulating dietary protein and lipid levels, Woolley (2009) investigated the P:E requirements of juvenile *A. japonicus* using variable P:E ratios (2.1–2.5 g protein/kJ/kg). In terms of production efficiencies (Table 3), a high protein/high fat diet (48 percent protein; 18 percent lipid; P:E ratio: 2.3) provided the highest growth rate (specific growth rate (SGR) of 1.1) and an FCR of 1.05:1 that was similar to the high protein:low fat combination. The formulation costs of this diet were, however, the highest of all the formulations in the trial. In contrast, with a SGR of 0.64 and an FCR of 1.93:1, the low protein:high fat combination (42 percent protein; 18 percent lipid; P:E ratio: 2.1) elicited the poorest production efficiencies. Thus, an increase in dietary protein level of just 6 percent, and a concomitant reduction in the P : E ratio of 0.2 resulted in a reduction in the SGR by 0.46 and an increase in the FCR of 0.88:1. With respect to the economic efficiencies of using these two formulations, using the optimal diet (high protein:high fat; P:E ratio 2.3) results in an annual feed requirement of 631 tonnes, which increases to 1 158 tonnes when the poorest performing dietary formulation is used. Feed costs as a percentage of operational costs using the optimum formulation represent 37.9 percent of total operational costs, a figure that increases to 48.7 percent when the poorest formulation is used. With respect to the IRR calculated over a ten-year period, the difference between the two formulations is 28.8 percent. While this analysis only relates to the manipulation of the dietary P:E ratios, it demonstrates that even relatively subtle changes to dietary formulations can have significant implications on the economic efficiency of the farming operation. Further, it should be noted that feed formulation may also affect the quality and hence the price of the farmed fish, and thus farmers need to take cognisance of the quality and price of the final product when they assess the most suitable formulation to use.

TABLE 3
Dietary protein energy ratios and the effect that these dietary formulations have on the economic efficiency of a 600 tonne per year farm

Diet	High protein low fat	High protein high fat	Low protein low fat	Low protein high fat
Protein (%):lipid (%)	48 : 6	48 : 18	42 : 6	42 : 18
Protein:energy ratio (P:E) (g protein/kJ/kg)	2.5	2.3	2.3	2.1
Feed conversion ratio (FCR)	1.05:1	1.05:1	1.31:1	1.93:1
Specific growth rate (SGR) (% body weight/day)	0.95	1.1	0.96	0.64
Cost/kg (US$)	1.41	1.43	1.35	1.37
Feed (tonnes per year)	631	631	787	1 158
Cost of feed (% operational costs)	37.2	37.9	41.4	48.7
Total capital (US$)	3 585 764	3 633 528	3 703 660	4 112 370
Internal rate of return (IIR) (%)	26.6	28.8	21.6	0.0

3.4 Scenario 4 – Feed management

Feed management practices play an instrumental role in ensuring that feed use is optimized. To ensure maximal growth, fish require a species and size-specific daily ration (Chua and Teng, 1982). In this regard, the feeding frequency and the ration that is delivered are important considerations. Increasing the feeding frequency and ration above the level that is required for optimal growth will result in poorer FCR. Thus, the best feeding regimen is the one that uses the lowest feeding frequency at which the daily ration can be provided without reducing growth or increasing FCR (Chua and Teng, 1982).

Collette (2007) undertook a study to determine the optimal ration and feeding frequency for juvenile *A. japonicus* (Table 4). It was established that feeding three times a day at a ration of 3.4 percent body weight (BW)/day produced the best results in terms of feed efficiency (FCR). While feeding to satiation three times a day produced a marginally higher growth rate, satiation feeding meant that the fish ingested 4.93 percent BW/day. The increased ration resulted in an increase in the FCR in this group. Indeed, feeding to satiation once, twice and three times a day resulted in a gradual increase in ration and a concomitant increase in FCR.

TABLE 4
Feed management practice and the impact that this has on the economic indicators of a 600 tonne per year farm

Feed rate	3 x daily @ 3.4% body weight/day	1 x daily satiation	2 x daily satiation	3 x daily satiation
Feed conversion ratio (FCR)	0.91:1	1.09:1	1.1:1	1.31:1
Specific growth rate (SGR) (% body weight/day)	3.75	3.02	3.61	3.76
Feed (% body weight/day)	3.41	3.28	3.96	4.93
Feed (tonnes per year)	546	654	660	787
Feed cost (US$)	743 039	889 097	898 179	1 069 649
Cost of feed (% operational costs)	34.9	38.5	39.0	42.5
Total capital (US$)	3 507 578	3 565 692	3 666 277	3 884 129
Internal rate of return (IIR) (%)	33.2	24.0	27.3	20.0

Feeding three times a day to a given ration based on BW was biologically and economically the most efficient feed management practice (Table 4). Based on a production volume of 600 tonnes per year, feeding three times a day at a ration of

3.4 percent BW/day would require 546 tonnes of feed; this requirement increased to 787 tonnes when the fish were fed to satiation three times a day. This increase in feed requirement increased feed costs by 44 percent and reduced the IRR of the investment from 33.2 percent to 20 percent. Thus, by simply feeding three times a day to a restricted ration based on BW, as opposed to feeding to satiation three times a day, there is a significant effect on the economic efficiency of the operation. It is therefore reasonable to conclude that simple changes to feed management practices can significantly improve the financial viability of a farming operation.

3.5 Scenario 5 – Tilapia culture systems

A comparison of the impact that feed management practices have on the economic efficiency of intensive and semi-intensive tilapia pond culture systems was undertaken. The comparisons were based on production parameters and associated costs for Nile tilapia (*Oreochromis niloticus*) production in Egypt (El-Sayed, 2010). The production parameters were incorporated into the 'User-friendly Aquaculture Investment and Management Tool' developed by FAO (Valderrama and Hishamunda, 2010). The Tool is an interactive, user-friendly model designed within Excel which enables users to conduct a complete financial analysis of a proposed or already-functioning aquaculture operation. User input data on production and economic characteristics of the aquaculture operation, including the size of the farm, the number of ponds, stocking densities, food conversion ratios (FCR), survival rates, the price of fingerlings and feeds, and selling prices, and an estimate of the investment required to build the facility, including the construction of the grow-out units (e.g. ponds) and the purchase of land and machinery is required. Based on the information provided, the model calculates enterprise budgets, income statements, a balance sheet and cash flow budget. The model was used to analyze feed production costs that were based on projected feed conversion ratios and feed costs accruing to the different feed types. The model outputs were used to develop a benefit-cost analysis. The production models were based on a single farmer model operating a 1 ha farm and producing fish of 200 g at a survival rate of 85 percent. The farm-gate price of the fish was estimated at US$2/kg. The intensive production model was based on a stocking rate of 5 fish/m^2 and a production of 14.5 tonnes/ha/year (Table 5). In contrast, the semi-intensive production model was based on a stocking rate of 2 fish/m^2 and a production of 5.8 tonnes/ha/year (Table 6).

Two feed types (extruded and pressed pellets) are used in intensive tilapia production systems in Egypt (El-Sayed, 2010). With respect to feed conversion, the use of extruded feeds typically results in FCR of 1:1–1.2:1. (Table 5) In contrast, the pressed feeds elicit FCR of between 1.2:1 and 1.5:1, indicating that they are nutritionally less efficient than the extruded feeds. With respect to the economic efficiency of their use, the extruded pellets are more expensive than the pressed pellets, and thus farmers need to be aware of the trade-off between using the relatively expensive extruded feeds that elicit higher feed efficiencies and the use of the cheaper, less efficient pelleted feeds. Using FCR as an indicator of feed management, the yields and benefit-cost ratios that accumulate to the use of the two feed types are presented in Table 5. At FCR that range between 1:1 and 1.2:1, the feed costs associated with the use of the extruded feeds range between US$7 892 and US$9 470/ha/year. In contrast, at FCR of 1.2:1 to 1.5:1, the feed costs associated with the use of pressed pellets range between US$6 873 and US$8 592/ha/year. At an FCR of 1.2:1, the feed costs associated with the use of the pressed pellets is approximately 37.8 percent less than that associated with using the extruded pellets. In terms of yields, the use of the extruded feeds yields a return of US$9 983 to 11 565/ha/year at a benefit-cost ratio of 0.84 to 1.12, while the pressed pellets produce a yield of US$10 864 to 12 585/ha/year at a benefit-cost ratio of 0.99 to 1.36. Evidently, while the pressed feeds are nutritionally less efficient than the extruded feeds, and assuming that they are used in the most efficient manner and elicit an FCR of 1.2:1,

their lower cost outweighs the poorer performance, and thus in terms of maximizing the economic returns, their use would represent the most attractive option to the farmers.

TABLE 5
Feed type and use in intensive tilapia pond culture systems. Production based on a 1ha farm model stocked at a rate of 5 fish/m² and a production of 14.5 tonnes/ha/year

Feed conversion ratio (FCR)	Feed type[1]	Feed requirement (kg/ha/year)	Feed cost (US$/ha/year)	Total operational costs (US$/ha/year)	Yield (US$/ha/year)[2]	Benefit-cost ratio[3]
1.0:1	E	14 143	7 892	10 292	11 565	1.12
1.1:1	E	15 557	8 681	11 082	10 775	0.97
1.2:1	E	16 971	9 470	11 874	9 983	0.84
1.2:1	P	16 971	6 873	9 273	12 585	1.36
1.3:1	P	18 386	7 446	9 846	12 011	1.22
1.4:1	P	19 800	8 019	10 419	11 438	1.10
1.5:1	P	21 214	8 592	10 993	10 864	0.99

[1] For the purpose of the analysis, average prices of US$550 per tonne and US$405 per tonne were used for extruded (E) and pressed (P) pellet feeds, respectively.
[2] Yield is calculated as the value of the fish produced per hectare per year.
[3] Benefit-cost ratio calculated as farm income (yield)/total operational costs.

The economic implications of applying semi-intensive farming practices are presented in Table 6. FCR using this farming system range between 1.31 and 1.8:1 (El-Sayed, 2010), and in comparison to employing intensive culture practices (Table 5), feed requirements and yields are significantly lower, and the total operational costs are approximately halved. Based on a production of 5.8 tonnes/ha/year the benefit-cost ratios under all feed conversion scenarios in semi-intensive farming practices (Table 6) are lower than those observed in the intensive systems (Table 5), indicating that the intensive systems are more economically efficient. Thus, while input costs of the intensive systems are higher, returns are greater than in the semi-intensive system; thus to optimize outputs, farmers should be encouraged to intensify their farming practices. It should be noted that this analysis addresses only feed use and costs, and does not take into consideration additional risks and costs that may add to the intensification of the production systems. For example, intensification of the production system may increase the potential for disease transmission, and result in increased mortality rates. These risks and costs should also be taken into consideration when determining the level of farming intensity.

TABLE 6
Feed (pressed pellets) and fertilizer use in semi-intensive tilapia pond culture systems. Production based on a 1 ha farm model stocked at a rate of 2 fish/m² and a production of 5.8 tonnes/ha/year

Feed conversion ratio (FCR)	Feed Requirement (kg/ha/year)	Feed cost (US$/ha/year)[1]	Fertilizer cost (US$/ha/year)	Total operational costs (US$/ha/year)	Yield (US$/ha/year)[2]	Benefit-cost ratio[3]
1.3:1	7 443	3 015	272	5 005	3 738	0.75
1.4:1	8 016	3 246	272	5 238	3505	0.67
1.5:1	8 589	3 478	272	5 470	3 272	0.60
1.6:1	9 161	3 710	272	5 703	3 040	0.53
1.7:1	9 734	3 942	272	5 942	2 807	0.47
1.8:1	10 306	4 174	272	6 170	2 573	0.42

[1] Feed used in the analysis were pressed pellets costing US$405 per tonne.
[2] Yield is calculated as the value of the fish produced per hectare per year.
[3] Benefit-cost ratio calculated as farm income (yield)/total operational costs.

4. CONCLUSIONS

It is evident that optimizing feed use plays a significant role in maximizing the economic efficiency of a farming operation. In this regard, farmers need to consider a number of factors that affect on-farm feed utilization. Principal among these factors are systems design (e.g. extensive *versus* intensive farming systems), operational parameters (e.g. temperature, water quality), feed type and formulation (extruded *versus* pressed pellets, ingredient inclusion levels) and feed management practices (e.g. feeding schedules).

With respect to controlling the use of aquafeeds, policy-makers and regulators have a number of tools at their disposal. While interventions should promote environmental protection, they also need to be practical, be cognisant of the implementation and compliance costs, and the ability of the specific country or farming sector to absorb these costs. The potential impacts that the regulations could have on sectoral growth also need to be considered. The sector is characterized by a multitude of production systems, species, feed types and culture environments, and no single policy or regulatory dispensation can be applied to all cases. Thus, regulators need to assess interventions on a case by case basis. Tacon and Forster (2003) advocated the use of regulations to control effluent streams, as opposed to feed and feed management. The argument presented by these authors was that there are many ways to supply nutrients and managing these nutrients within the farm environment; and that the net effect of applying good farm management practices is that they will not negatively affect the environment. As poor feed management practices often manifest themselves in the effluent streams – particularly in cases where effluent treatment is also substandard – it would appear that, where practicable, effluent monitoring would provide a suitable vehicle with which to promote sustainable feed management practices while placing minimal regulation on the farming practice.

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This technical paper provides a comprehensive review of on-farm feeding and feed management practices in aquaculture. It comprises of a) ten case studies on feeding and feed management practices carried out in seven selected countries of Asia and Africa for eight species that belong to four major farmed species of freshwater finfish and shellfish; b) an analysis of the findings of the above ten case studies and a separately published case study for Indian major carps carried out in India; c) ten invited specialist reviews on feed management practices from regional and global perspectives; and d) an overview of the current status of feed management practices.

The broad thematic areas that were addressed in these case studies and invited reviews are i) current feed types (including fertilizers) and their use in semi-intensive and intensive farming systems; ii) on-farm feed production and management; iii) feeding and feed management strategies, feed procurement, transportation and storage; iv) environmental, economic, regulatory and legal frameworks of feeding and feed management practices; and iv) identification of research needs. Based on the information presented in the eleven case studies, ten specialist reviews and from other relevant publications, an overview paper presents concluding remarks and recommendations on some of the major issues and constraints in optimizing feed production, use and management.