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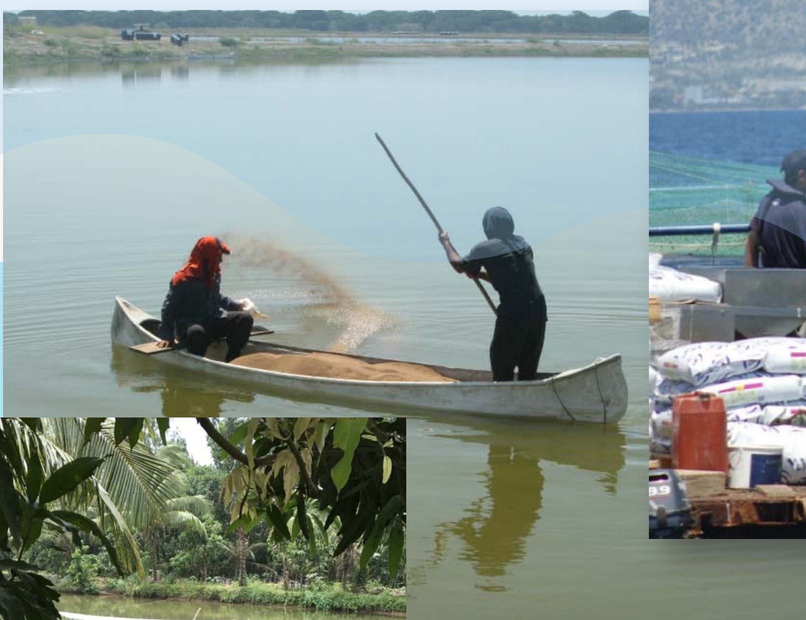
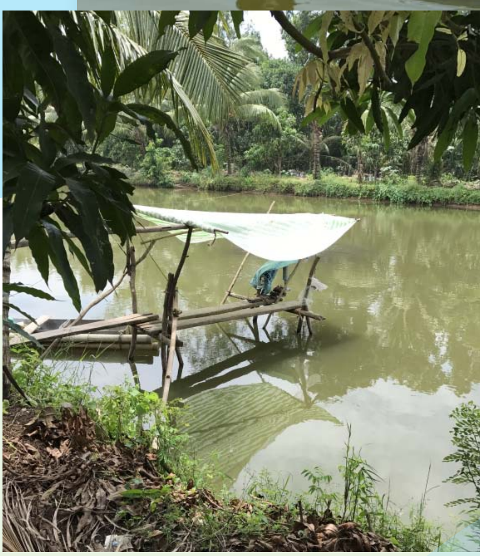
IMPROVING FEED CONVERSION RATIO AND ITS IMPACT ON REDUCING GREENHOUSE GAS EMISSIONS IN AQUACULTURE





Cover photographs:

Front cover
Top: Feeding of Atlantic salmon (*Salmo salar*) by automatic feeder, Chile (courtesy of Michael Adler). *Middle*: Hand feeding of marine shrimps (whiteleg shrimp *Litopenaeus vannamei* and blue shrimp *Penaeus stylirostris*) in Ecuador (courtesy of Laurence Massaut). *Bottom*: A wooden platform with manually operated feeding apparatus in a small family-run striped catfish (*Pangasianodon hypophthalmus*) farm near Long Xuyen City, An Giang Province, Viet Nam (courtesy of FAO/Mohammad R. Hasan).

Back cover
Hand feeding of marine shrimps (whiteleg shrimp *Litopenaeus vannamei* and blue shrimp *Penaeus stylirostris*) in Ecuador (courtesy of Laurence Massaut).

Cover design:
Mohammad R. Hasan and Jose Luis Castilla Civit.

IMPROVING FEED CONVERSION RATIO AND ITS IMPACT ON REDUCING GREENHOUSE GAS EMISSIONS IN AQUACULTURE

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 2017

ISBN 978-92-5-109886-8

This publication has been printed using selected products and processes so as to ensure minimal environmental impact and to promote sustainable forest management.

Preparation of this document

This FAO Non-Serial Publication was prepared under the coordination of Dr. Mohammad R. Hasan of the Aquaculture Branch, FAO Fisheries and Aquaculture Department. It was compiled, along with a series of presentation available online, as a part of FAO's Strategic Objective (SO2) to: Increase and improve provision of goods and services from Agriculture, Forestry and Fisheries. Specifically, this publication contributes to the organizational outcome 2011 that aims to have: producers and natural resource managers adopt practices that increase and improve the provision of goods and services in agricultural sector production systems in a sustainable manner. The rationale of the work undertaken was to i) assess the current GHG contributions of aquaculture, related to feeds and feeding, and understand ways to measure it; ii) explore current potential for reducing Feed Conversion Ratio (FCR) for a range of important and commercially significant species, and therefore continuing to improve their environmental performance including reductions in GHG and iii) explore potential transfer of feed and feeding technologies and lessons learnt from the well-developed salmon farming industry to other freshwater and marine species such as carps, catfishes, tilapia and shrimps.

The activity undertaken and publication of this document were partially funded under the auspices of the project "*Climate change, fisheries and aquaculture: testing a suite of methods for understanding vulnerability, improving adaptability and enabling mitigation* (GCP/GLO/322/NOR)", supported by the Government of Norway, while the FAO/GSI (Global Salmon Initiative) workshop was hosted by Biomar on behalf of GSI with the support of Aquacorporación Costa Rica.

Preliminary compilation of the workshop report and initial data gathering for the GHG tool was undertaken by Mr Jonathan Moir. The GHG tool was developed by Dr Michael MacLeod, with inputs from several colleagues from FAO and elsewhere. For consistency and conformity, scientific and English common names of fish species were used (FishBase www.fishbase.org/search.php).

Dr. Richard Anthony Corner is acknowledged for general technical editing, Ms. Marianne Guyonnet and Ms. Danielle Rizcallah for their assistance in quality control and FAO house style. Mr. Jose Luis Castilla Civit prepared the layout design for printing. The publishing and distribution of the document were undertaken by FAO, Rome. Finally, Dr. Malcolm Beveridge, Head of the Aquaculture Branch of the FAO Fisheries and Aquaculture Department is acknowledged for providing the necessary support, advice and insight to complete this publication.

Abstract

This document presents in Section A the narrative report of the outcomes from an FAO/GSI (Global Salmon Initiative) Joint Workshop on "Reducing Feed Conversion Ratios in the Global Aquaculture to reduce carbon and other footprints and increase efficiency" including conclusion and recommendations. Section B provides summaries of the technical presentations given at the workshop. Section C provides a link to a compendium of the workshop PowerPoint presentations that was presented in the workshop (available online) and Section D summarizes FAO's spreadsheet-based (Excel™) tool for quantifying greenhouse gas emissions arising from aquaculture, with a web-link to be able to download the application. The FAO/GSI Joint Workshop was held in Liberia, Costa Rica from 9 to 11th November 2015. The meeting, convened by FAO and hosted by Biomar on behalf of GSI with the support of Aquacorporación Costa Rica, was attended by international experts from Asia, Africa, Europe, North America and South America, representing global areas where carp, catfish, tilapia, marine shrimp and salmon farming are undertaken. The meeting was organized with three major objectives: i) assess the current GHG contributions of aquaculture (specifically related to feeds and feeding) and ways to measure it; ii) explore concerted actions to reduce FCR in the global aquaculture industry and; iii) explore potential transfer of feed and feeding technologies and lessons learn from salmon farming to other species such as carps, catfishes, tilapia and marine shrimps.

The workshop convened in both plenary and a working group. Presentations given at the workshop included reviews, research and case studies on factors affecting FCR and GHG, as well as an introduction to the FAO's tool for quantifying GHG from aquaculture. Group discussions and deliberations identified several factors that impact FCRs, particularly in species farmed in developing countries, which could be targeted through programs that would improve sustainability and ultimately reduce GHG and other emissions. In the final plenary session, the participants concluded that critical components in managing environmental control will impact FCRs and GHG emissions, including i) maximizing oxygen levels in rearing for tropical species such as carps, catfishes, tilapia and marine shrimps; ii) use of technologies to simplify farm management through improved farm monitoring systems; iii) better control and reduction of mortality and unregistered losses; and iv) provision of adequate and economically acceptable diets and good feed management. A set of recommendations was developed to overcome constraints that will guide the FAO Fisheries and Aquaculture Department Aquaculture Branch (FIAA)'s future work in this area.

Hasan, M.R. & Soto, S. 2017. Improving feed conversion ratio and its impact on reducing greenhouse gas emissions in aquaculture. FAO Non-Serial Publication. Rome, FAO. 33 pp.

Contents

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Abbreviations and acronyms

AFFRIS	Aquaculture Feed and Fertilizer Resources Information System
bFCR	biological feed conversion ratio
CC	carbon capture
CP	crude protein
DO	dissolved oxygen
EF	emission factor
eFCR	economic feed conversion ratio
EI	emissions intensity, i.e. the emissions per unit of output, e.g. kgCO_2e/kg LW
FAO of UN	Food and Agriculture Organization of the United Nations
FCR	feed conversion ratio
FIAA	Aquaculture Branch of the FAO Fisheries and Aquaculture Department
g	gram
GHG	greenhouse gas
GSI	Global Salmon Initiative
ha	hectare
kg	kilogram
km	kilometer
LCA	life-cycle assessment
LUC	land use change
LW	live weight e.g. kgCO_2e/kg LW
R&D	research and development
SGR	specific growth rate
tFCR	theoretical feed conversion ratio

Section A: Report of the FAO/GSI Joint Workshop on "Reducing Feed Conversion Ratios in the Global Aquaculture to reduce carbon and other footprints and increase efficiency"

BACKGROUND TO THE WORKSHOP

The issue: contribution of feed conversion ratio (FCR) to carbon footprint in aquaculture

In 2013, about 48 percent of global aquaculture production (of all species – fish, shellfish, algae, other) relied on some sort of feed input (commercial feeds, farm-made feeds, fresh feeds) (Hasan, 2015). It is likely this percentage will continue to increase, as production growth in fed-species outstrips that for non-fed species.

In general feeds account for 50 to 80 percent of energy consumption in intensive systems through sourcing of raw materials, feed production and transport. Feed accounts for almost 100 percent energy use in semi-intensive systems, which, albeit not fully dependent on feeds, has few other energy inputs. Thus, feeds are likely to be the main sources of greenhouse gases (GHG) in the aquaculture sector[1].

The largest part of feed-related energy use is associated with the supply of raw materials, including in many cases, inputs of fishmeal and oil, where interactions with capture fisheries are most significant. Feed associated inputs can be particularly but not exclusively linked with fishmeal and oil components, where fuel and energy associated with capture and processing can be significant. The levels are linked with the fishery resource, the nature of processing and the transport and distribution costs involved. Given global aquaculture production and the use of fishmeal even in the freshwater species, it has been estimated that Asia takes an increasing proportion of fishmeal in diets for production of carps, catfishes and tilapia,. Even though the amount used per tonne of fish produced is small, because of the large

1 Aquaculture ponds can also contribute to GHG emissions through methane and nitrous oxide emission, however. Ponds could also contribute to carbon fixation and the balance is likely dependent on the management, species, environmental conditions etc. Not enough is known yet on this and hopefully it will be a second stage of this initiative.

biomass being produced it accounts for more than a third of the total fishmeal being consumed by aquaculture today (Cao *et al*., 2015). There is, however, a concerted effort to reduce fishmeal and fish oil in diets and raw material feed inputs from conventional agriculture, are becoming increasingly important and have definable fuel and energy use profiles. In less intensive systems, industrial energy associated with inorganic fertilizer production may also contribute to inputs. The use of aquafeed originated from vegetable sources is expected to reduce the GHG emissions, but the use of agri-produced feed ingredients, such as soy, can indirectly be a significant contribution to greenhouse gas (GHG), if soy plantations have replaced forest, for example. Accurate data on energy inputs associated with feeds from all sources require further studies, and FAO is working on this, particularly in the context of reducing feed conversion ratios.

Feed conversion ratio (FCR), in its simplest form a comparison of the amount of feed used per unit weight gain of the species being grown, offers a measure of aquaculture production efficiency. It also indicates environmental performance, since it provides an indication of the undesirable outputs and lost nutrients to the environment, with potential consequences such as accelerated eutrophication, loss of biodiversity and other ecosystem services (Waite *et. al*., 2014).

The contribution of aquaculture to GHG emission is strongly related to FCR and the origin of the feed components, but is still comparatively low for many aquaculture systems. Salmon production has one of the lowest FCR of all species, and considering the shift towards terrestrially-produced raw materials (and provided these do not have large carbon foot prints) their impact on GHG has shown to be smaller (per tonne of fish produced), even than other species produced through aquaculture, such as freshwater species (Waite *et al.,* 2014). Salmon farming managed to reduce the FCR from about 2.8 to approximately 1.2 in less than 30 years thanks to technological developments, training, and better feed and on-site management.

SCOPE AND ORGANIZATION OF THE WORKSHOP

FAO, with support from the Government of Norway and in conjunction with the Global Salmon Initiative (GSI), organized an expert meeting to analyse the potential for reducing aquaculture GHG contributions and increasing sustainability of aquaculture feeding systems through the reduction of FCR.

Purpose of the workshop

The workshop aimed to:

- assess the current GHG contributions of aquaculture related to feeds and feeding and ways it can be measured;

- explore concerted actions to reduce FCR in the global aquaculture industry; and
- explore potential transfer of feed and feeding technologies and lessons learn from salmon farming to other species such as carps, catfishes, tilapia and marine shrimps.

Participants at the workshop discussed the following critical issues: a) current knowledge on GHG contribution of aquaculture and its relationship to FCR within important aquaculture systems; b) FCR as an environmental and economic indicator, including its role in the assessment and mitigation of GHG; c) ways to improve FCR and transfer technological pathways from salmon to other systems; d) improving feeding process to reduce environmental footprint and improve profitability, especially means to do this for small farmers; and e) the overall global impact of a significant joint effort to reduce FCRs, with a comparative perspective with other food systems.

Participants and the workshop venue

The meeting took place in Liberia, Costa Rica from 9 to 11th November 2015, at the Hotel El Mangroove, in the Gulf of Papagayo, Guanacaste.

The meeting was hosted by Biomar on behalf of GSI, with the support of Aquacorporación Costa Rica. The meeting was attended by 17 international experts from Asia, Africa, Europe, North and South America representing carp, catfish, tilapia, marine shrimp and salmon farming.

The workshop

The workshop agenda and timetable are presented in Appendix I, with the list of participants in Appendix II. Presentations were made on 9 November and concluded in midday on 10 November. Abstracts of all presentations made can be found in Section B of this document, and the link to workshop presentations in Section C, for further reading and understanding.

Initial presentations focused on global and regional aspects of feeds and feeding in aquaculture and their role on the GHG emissions and the impact of FCR on these emissions. These were followed by presentations on specific countries and aquaculture systems that described in detail the current situation with regards to FCR and the trends seen in recent years, and main factors affecting the feed use efficiency.

The detailed description of experiences and lessons learn in salmon farming, both from a feed manufacturer and from a farm management perspective, were used to identify critical turning points in improving FCR through time. Such experiences were compared with those in carps, catfishes, tilapia, and marine shrimps.

The group discussion then developed the significant themes identified during the presentations. Rather than create small breakout groups to address individual issues the participants opted to address each item as a whole group, drawing together relevant conclusions, which are listed below.

CONCLUSIONS AND RECOMMENDED ACTIONS

Conclusions

The expert meeting was finalized with a plenary discussion of the main themes identified through the presentations and by the group discussion.

The primary conclusion was that there is relevant room for improvement of FCR in global aquaculture, and especially in freshwater species production. A global concerted action could improve sustainability of the freshwater sector, improving production while releasing pressure on feed resources, and improve competitiveness, especially of smallholders and other small fish producers.

A thorough discussion of the factors affecting FCR concluded that its four main drivers, being genetics, environment, husbandry and feeds, are nonetheless extremely complex issues for which there are no simple solutions, and are areas of significant continued research worldwide. The intersection of these parameters, however, and their interaction with environmental factors, particularly oxygen saturation and temperature, opens some avenues where significant gains can be made through simple and inexpensive means. Specific conclusions are summarized below.

Management and environment

- Managing certain environmental aspects such as optimizing oxygen levels in rearing systems could significantly improve FCR in more tropical production systems, for species including carps, catfishes, tilapia and marine shrimps.
- Introduction of monitoring systems to optimize feeding and reduce FCR would be a good step at improvement.
- Introduction of farm monitoring systems to simplify farm management is a key factor that could have a major impact, including potentially leveraging high-tech industries to develop smart phone based systems for remote application and monitoring.
- Use of associations and government outreach programs could be enhanced, as a means to introduce means and methods of record keeping to farmers, particularly small-scale farmers.

Mortality

- Mortality and unregistered losses were identified as major factors contributing to GHG emissions, because it impacts FCR and feed use requirements.

- In many systems accurate inputs (e.g. quantity of fish biomass stocked, feed use records) and outputs (mortalities) are not accurately quantified, primarily because methods to do so are not well-developed, and therefore there is a need to establish appropriate methods to quantify these inputs accurately, as this directly affects feed use and consumption.
- Introduction of biomass estimation and accurate feeding requirements could be undertaken with appropriate training programs.

Feeding and feed management

- The development and use of feed tables were identified as a useful method of maintaining strong stock management.
- The training and motivation of staff who undertake feeding was identified as important to securing economic success, maintaining feed discipline and control and reducing FCR.

Feed performance

- Many of the tropical species being farmed do not have feeding standards that are system specific, and these need to be developed.
- Provision of adequate diets and feed management controls, that are also economically acceptable, will also impact FCRs.

Waste management

- Good control of waste management and its impacts affects economic performance, and efforts should be made to reduce waste.
- Good waste management impacts GHG emissions directly, through maintaining control over reducing feed wastage, and mortality reduction.

Output

The meeting drafted a global plan including:

1. Environmental management:
Developing a better understanding of dissolved oxygen (DO) and water temperature at farm level
This will require several actions to include:
   a. A global assessment of the status and knowledge of dissolved oxygen and water temperature situations in tropical farming systems and the impact of their interactions;
   b. A global plan to improve environmental oxygen monitoring and optimizing oxygen saturation in farming systems; and
   c. Evaluation of the impact of these actions on fish health, survival, growth, performance and efficiency (e.g. FCR and other indicators).

2. Feeding mode and feed management
Feeding practices and feed management are very controlled and sophisticated in the salmon farming industry. Developed over the last 30 years the

technology and practices have enabled the industry to reduce FCR, to current levels that are very close to 1:1. The experience inherent in the industry offers opportunities to transfer this technology to other farming sectors in a bid to reduce the FCR globally. This experience in feeding and feed management and rearing in salmon farming is resident in the FAO/GSI collaboration agreement. A bilateral exchange programme was proposed:

a. GSI could facilitate sending personnel to the field in developing countries and regions with established industries in fish and shrimp farming to assist in evaluating the potential to introduce these technologies to effect change.
b. GSI could host managers, both farmers and government assistance agencies, from developing countries and regions to visit salmon farms to be educated in the management approaches and technologies currently used in salmon farming worldwide.

3. Improved feed quality:

a. For feed producers, the expert group proposed to improve access and dissemination of information related to feed, such as databases of feed ingredients, information on digestibility, and other critical requirements. Such databases could be used by feed producers in developing countries and regions that do not have capacity for research and development to improve feed formulation and quality. At the same time, this allows the industry to maintain competitive pricing. FAO has a relevant database that could be expanded to include local products commonly available in various regions that are not already included in the database. This database is available at Aquaculture Feed and Fertilizer Resources Information System (AFFRIS) (www.fao.org/fishery/affris/en/).
b. For farmers, the expert group proposed that a manual or guide be prepared feed production. Such a manual would enable farmers to ask relevant questions, and to ask for clarifications where needed, particularly on feed composition and quality.

FARM VISIT

The workshop closed with a visit to tilapia farms, hosted by Aqua Corporacion Internacional SA, Cañas, Guanacaste (who's shareholders include: AquaChile & Biomar Aqua Corporacion Products SA); and a visit hosted by Biomar to their aquafeed factory at Cañas, that produces feeds for tilapia and other tropical species grown in Central America.

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An intensive tilapia farm managed by Aquacorporacion Internacional (ACI) in Liberia, Costa Rica
COURTESY OF FAO/MOHAMMAD R. HASAN

Appendix I: Workshop agenda and timetable

LIBERIA, COSTA RICA, 8–11TH NOVEMBER 2015

Time/Date	ACTIVITIES
8 November - Arrival of participants in Liberia	
9 NOVEMBER - WORKSHOP DAY 1	
Opening and welcome remarks	
09:00	Welcome - Doris Soto, Food and Agriculture Organization (FAO) and Michael Adler, Global Salmon Initiative (GSI)
09:10-10:30	**Presentations**
	Objectives of the workshop: the need to address energy issues, GHG emission and mitigation and FCR in aquaculture - *Doris Soto, Senior Aquaculture Officer, Aquaculture Branch (FIAA), Fisheries and Aquaculture Policy and Resources Division, Fisheries and Aquaculture Department, FAO, Rome, Italy (10 min)*
	Feeding the global aquaculture: supply and demand of feed and feed ingredients - *Mohammad R. Hasan, Aquaculture Officer, Aquaculture Branch (FIAA), Fisheries and Aquaculture Policy and Resources Division, Fisheries and Aquaculture Department, FAO, Rome, Italy (30 min)*
	Commercial decisions: balancing between FCR and feed cost - *David H.F. Robb, FAO Consultant, 24 Moubray Gardens, Cambus, Clackmannanshire FK10 2NQ, United Kingdom (20 min)*
10:30-11:00	**Coffee break and group photo**
11:00-13:00	**Presentations**
	Historical overview of FCRs for farmed striped catfish (*Pangasionodon hypophthalmus*) in Viet Nam: a case study - *Nhu Van Can, Vice Director, Department of Agriculture and Rural Development, Dong Thap province, Viet Nam (20 min)*
	Nile tilapia in Bangladesh and striped catfish in Viet Nam: perspectives on farming and FCR - *David F.H. Robb, FAO Consultant, 24 Moubray Gardens, Cambus, Clackmannanshire FK10 2NQ, United Kingdom (30 min)*
	Greenhouse gas emissions from Indian major carp farming in India - *Rajendran Suresh, FAO Consultant, 78A, 9th Cross, Arulanada Ammal Nagar, Thanjavur 613 007, Tamil Naidu, India (20 min)*
	Life cycle assessment of three freshwater species in Asia and its implications on GHG emissions and FCR - *David H.F. Robb, FAO Consultant, 24 Moubray Gardens, Cambus, Clackmannanshire FK10 2NQ, United Kingdom (30 min)*

13:00-14:00	**Lunch**
14:00-15:30	**Presentations continue**
	Quantifying GHG emissions in aquafeed and identifying mitigation opportunities: *Michael Macleod, Senior Researcher, Land Economy, Environment and Society Group, SRUC, King's Buildings, Edinburgh, United Kingdom (30 min)*
	A tool to assess GHG contribution in aquaculture: salmon and other species as cases studies: *Jonathan Moir, FAO Consultant, AquaGem Inc. 156 Waterford Br. Road, St. John's, Newfoundland, Canada A1E 1C9 (30 min)*
	The role of FRC as a performance indicator - *Doris Soto, Senior Aquaculture Officer, Aquaculture Branch (FIAA), Fisheries and Aquaculture Policy and Resources Division, Fisheries and Aquaculture Department, FAO, Rome, Italy (20 min)*
15:30-17:30	**Presentations continue**
	Improving feeds and FCRs: the perspective from salmon farming - *Michael Adler, R&D Manager, BioMar Americas, Bernardino 1981, Puerto Montt, Chile (30 min)*
	On reducing 'FCR' in semi-intensive Indian major carp culture in Andhra Pradesh, India - *Ramakrishna Ravi, Managing Trustee, FISHNEST-The Indian Fish Family, Eluru 534007, Andhra Pradesh, India (20 min)*
17:30-18:00	**General discussion and closing remarks**
20:00	**Welcome dinner**

10 NOVEMBER - WORKSHOP DAY 2

08:30-10:00	**Presentations**
	History of FCR reduction in marine shrimp and its impact in shrimp farming in Ecuador - *Laurent Masaut, Scientific Adviser, Cámara Nacional de Acuacultura, Centro Empresarial Las Cámaras, Torre B, 3er piso, Oficina 301, Av. Francisco de Orellana y Miguel H. Alcívar, Guayaquil, Ecuador (15 min)*
	Management of FCR: the perspective from the shrimp industry - *Roberto Lopez-Ibanez, NovaGuatemala, Pescanova, Ecuador (15 min)*
	Potential for reducing FCRs in the farming of native tilapias in Malawi - *Daniel M. Jamu, Aquaculture Production Consultant, Fisheries Integration of Society and Habitats Project, Mangochi, Malawi (15 min)*
	Application, interpretation and reduction of FCRs and consequences for major feed ingredients - *Krishen J. Rana, 3 Westerton Drive, Bridge of Allan, Stirling FK9 4AX, United Kingdom (30 min)*
10:30-11:00	**Coffee break**
11:00-11:30	Round table discussion
11:30-11:40	Presentation
	Main objectives of the workshop. *Doris Soto, Senior Aquaculture Officer, FAO, Rome (10* min)

11:40-13:00	Working group discussions
13:00-14:00	**Lunch**
14:00-15:30	Working group continues discussion
15:30-16:00	**Coffee break**
16:00-18:00	Plenary presentation of working group deliberations

11 NOVEMBER - WORKSHOP DAY 3

08:30-10:00	**Plenary discussion** - Developing a global strategy, steps and timeline - Recommendations to FAO and to industry
12:30	Closure of the workshop
13:00-14:00	**Lunch**
14:00-21:30	Farm and feed plant visit
14:00-15:30	Transportation to farm
15:30-16:30	Farm visit at Aquacorporacion Internacional (ACI)
16:30-17:00	Transportation to BioMar factory
17:00-18:00	Tour around BioMar factory
18:00-20:00	**Dinner at Restaurant La Pacifica**
20:00-21:30	Return to hotel

12 NOVEMBER - DEPART LIBERIA

Rearing tanks of an intensive rainbow trout farm, Ermstalfischerei, Germany

COURTESY OF JAYANTA SAHA

Hand feeding of one-year-old fish in an intensive rainbow trout farm, Ermstalfischerei, Germany

COURTESY OF JAYANTA SAHA

Appendix II: List of participants

LIBERIA, COSTA RICA, 8–11TH NOVEMBER 2015

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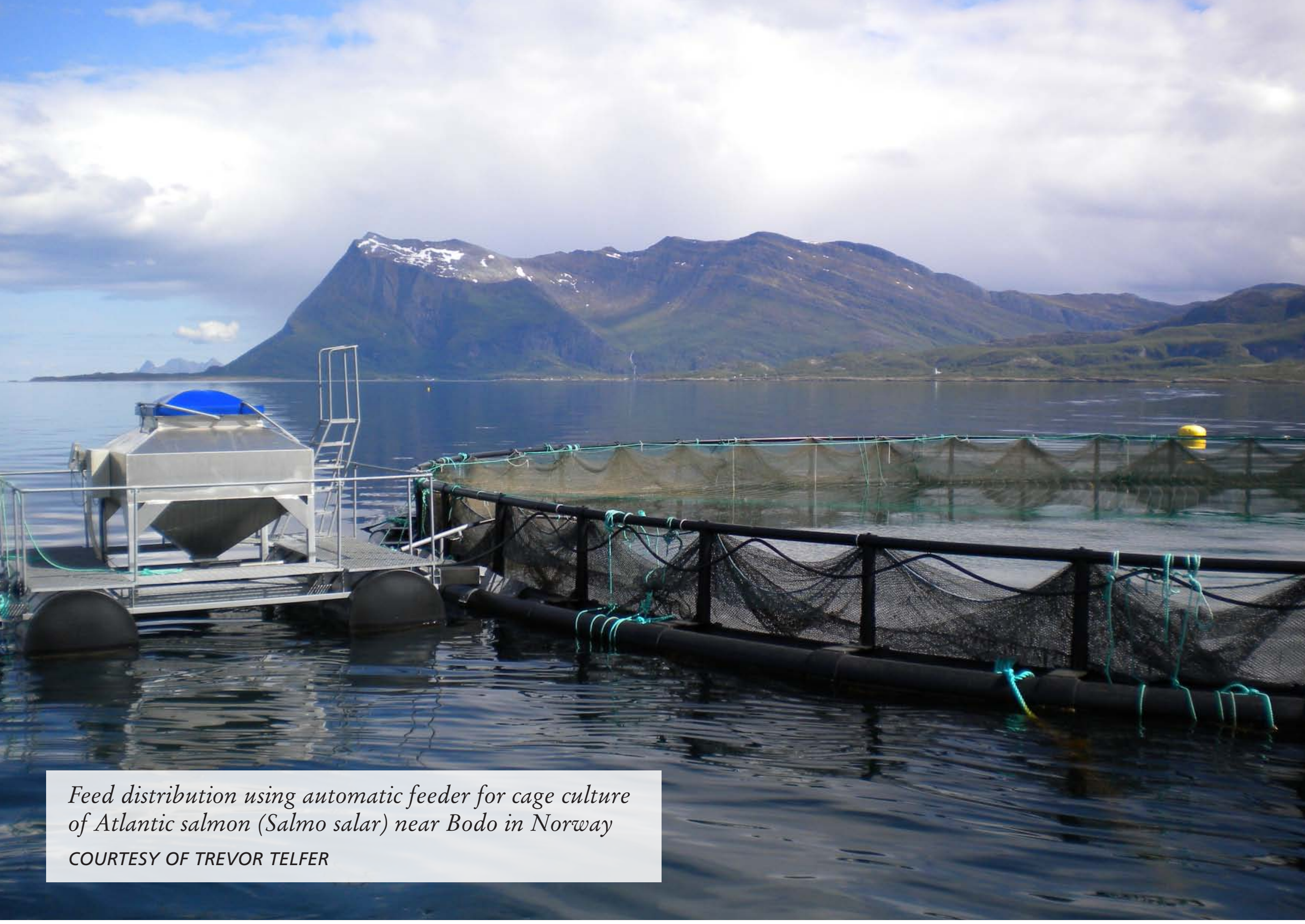

Feed distribution using automatic feeder for cage culture of Atlantic salmon (Salmo salar) near Bodo in Norway

COURTESY OF TREVOR TELFER

A farmer feeding his fish (striped catfish Pangasianodon hypophthalmus) with farm-made feed in his backyard pond, Mymensingh, Bangladesh

COURTESY OF FAO/NESAR AHMED

Section B: Summaries of Technical presentations

LIBERIA, COSTA RICA, 8–11TH NOVEMBER 2015

Objectives of the workshop: the need to address energy issues, GHG emission and mitigation and FCR in aquaculture

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The GHG contribution of fisheries, aquaculture and related supply chain features are being studied and they are relatively small in global terms. Fuel use alone in global capture fisheries generates around 140 million tonnes of CO_2 although estimates vary a great deal and data covers different parts of supply chain. A supply chain approach can identify hotspots for greenhouse gases (GHG) emissions. It is likely that fishing vessels are the largest GHG emitters in the sector, followed by processing plants.

Emissions from aquaculture seem relatively lower than fisheries, its main GHG emission comes from feed (thus involving fishmeal fisheries) followed by production and transport. In 2012 at least 65 percent of aquaculture production relied on some sort of feed and is likely that this percentage has risen today due to a greater increase in the production of fed species. In general feeds account for almost 80 percent of energy consumption in intensive systems and almost the entire use in the semi-intensive.

The reliance on fishmeal and fish oil is not sustainable in the long term and yet reliance on terrestrial inputs can also be a challenge, especially under carbon capture (CC) scenarios and freshwater stress. Terrestrial feed sources can also contribute to large GHG emission when feed inputs come from former forested lands that are now being cultured for feed ingredients such as soy.

It is very clear that more efficient feeding can reduce GHG emissions and that feed conversion ratios (FCRs) in aquaculture can be improved significantly, especially in global aquaculture bulk production species such as carps, catfishes and tilapia. The significant reduction of FCR in salmon farming can potentially be used as a model and the technology and know how could be transferred to less efficient systems. Thus, the objectives of the workshop were: (i) to discuss the potential for reducing aquaculture GHG contributions and increasing sustainability of aquaculture feeding systems in general, through reduction of FCR, specially using lessons learn from salmon industry and (ii) to discuss and

propose a plan of action to continue reducing FCR at global level for the sector through public–private cooperation, international cooperation and support.

Feeding the global aquaculture: supply and demand of feed and feed ingredients

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In 2013, global aquaculture production reached 97.2 million tonnes, 70.3 million tonnes of aquatic animals and 26.9 million tonnes of aquatic plants, growing at an average annual rate (APR) of 7.7 percent since 1995. 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 development of the poor.

During the period 1995 – 2013, production from feed-dependent aquaculture increased over fourfold from 12.2 to 46.1 million tonnes, largely through intensification of production methods. The use of aquatic species/species groups such as, carps, catfishes, tilapias, marine shrimps and salmonids with established aquaculture technologies provided firm market opportunities for increasing production and driving production efficiency. In 2013, about 46.1 million tonnes of farmed fish (including Indian major carps) and crustaceans (47.6 percent of the total global aquaculture production, including aquatic plants, or 65.7 percent excluding aquatic plants) was dependent upon the supply of external nutrient inputs provided in the form of fresh feed ingredients, farm-made feeds or commercially manufactured feeds. In 2013, fed aquaculture contributed to 85.7 percent of global farmed finfish and crustacean production of 53.8 million tonnes. During the period from 1995 – 2013, production of industrial aquafeed has increased from 7.6 to 42.6 million tonnes. These estimates took no account of the commercial feed used by Indian major carps, which are increasingly fed with commercial feed along with supplementary feeds.

Global fishmeal supplies have fluctuated between 4.5 million and 7.5 million tonnes for the last 38 years (1976 – 2013) and have now stabilized at about 5.0 million tonnes per year; production of fishmeal in 2013 being 4.92 million tonnes. Global fish oil supplies have fluctuated between 0.86 million and 1.67 million tonnes for the last 38 years (1976 – 2013) and have now stabilized at about 1.00 million tonnes per year, production of fish oil in 2013 being 0.91 million tonnes. Within the animal husbandry subsectors, aquaculture is now the largest user of fishmeal and fish oil. Fishmeal and fish oil are primarily used for the production of industrial aquafeed, it is estimated that about 10 percent of global fishmeal - that are used for aquaculture –

goes for production of farm-made aquafeed. The volumes of fishmeal and fish oil used in aquafeeds have grown – rising between 1995 and 2013 from 1.88 million tonnes to 3.80 million tonnes and from 0.47 million tonnes to 0.87 million tonnes, respectively. Although the use of fishmeal and fish oil in aquafeeds is more prevalent for higher trophic level finfishes and crustaceans (marine shrimps, marine fishes, salmons, freshwater crustaceans, trouts, eels) (fishmeal inclusion level varying between 18 and 40 percent and fish oil between 3 and 12 percent), low-trophic level finfish species/species groups (carps, catfishes, tilapias, milkfish, etc.) are also fed with fishmeal and fish oil at rates of between 2 and 5 percent.

Over recent decades, significant efforts have been made by the aquaculture industry to reduce the levels of inclusion of fishmeal and fish oil. The reduction of the feed conversion ratio (FCR) has played an important role in more efficient use of these inputs, which has largely been achieved through improved management. There has been a gradual reduction of fishmeal use in aquafeeds since 2006. In 2005, aquaculture consumed about 4.20 million tonnes (or 18.5 percent of total aquafeeds by weight) of fishmeal, reducing to 3.69 million tonnes in 2013 (or 8.7 percent of total aquafeeds by weight). It has been predicted that, even with increasing aquaculture production globally, the use of fishmeal for aquafeeds will decrease further to 3.49 million tonnes by 2020 (5.1 percent of total aquafeeds for that year). Nevertheless, for aquaculture to grow aquafeed production is expected to continue growing at a similar rate, to 69.0 million tonnes by 2020.

Although the discussion on the availability and use of aquafeed ingredients often focuses on fishmeal and fish oil resources (including low-value fish/ trash fish), considering past trends and current predictions, sustainability of the aquaculture sector is more likely to be closely linked with the sustained supply of terrestrial animal and plant proteins, oils and carbohydrate sources for aquafeeds. The aquaculture sector should therefore strive to ensure sustainable supplies of terrestrial and plant feed ingredients.

Commercial decisions: balancing FCR and feed cost

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Economic sustainability is of key importance to farmers, before environmental considerations, for example, are taken into account. The use of feed is an important cost to farmers, but is also accounts for the main use of resources in aquaculture.

The conversion of feed into harvested fish biomass is an important calculation, both economically and environmentally. Using more feed costs more money

and uses more resources, but also creates more waste, which will affect water quality and potentially the health and survival of fish being grown.

This paper discusses the drivers of the feed conversion ratio (FCR) and the drivers of the price of feed. Feed quality affects the price, but quality is not the only factor affecting FCR. Even if the FCR of a feed is improved under standardised conditions, farmers may not be prepared to pay a premium price for it under commercial conditions, as there are so many variables which may affect the final outcome at harvest. This leads to greater FCRs than could be achieved, but is a lower risk strategy economically. Improved management of the non-feed factors driving FCR will help reduce these risks and will encourage farmers to move to better feeds.

Historical overview of FCR for farmed striped catfish (*Pangasianodon hypophthalmus*) in Viet Nam: a case study

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The pangasius industry is well developed and is a major contributor (30 percent) to aquaculture production in Viet Nam. Pangasius is intensively farmed with high productivity and low production costs. Production is concentrated mainly in the five provinces of Mekong Delta that represent 92.2 percent of all farming areas and is highlighted by integrated enterprises & linkages among the value chain.

The present aquafeed value chain of pangasius is well-organized, minimizing unnecessary middle dealers, and direct feed mill to farmer interactions represents up to 43.3 percent of feed production. Feed is manufactured in modern facilities, producing dried floating pellets. The number and production capacity of feed manufactures is relatively high, creating a good competitive environment.

The major issues of feed industry are related to over production capacity, variability in crude protein (CP) content (22 – 30 percent) and relatively high FCR (1.57). In addition, low investment in R&D, training, capacity building for on-farm feeding and feed management have been recorded. Farmers, based on their experiences, manually feed at high frequency, which may lead to over feeding, and feed is a major contribution to pangasius production cost (80 percent).

To improve feed and feeding efficiency, it is suggested researches should focus on development of feed quality, i.e. appropriate formulation with highly digestible stable content of protein for different development stages of pangasius growth. Appropriate feeding regimes, feeding protocol, effective

feeding systems and on-farm feed management strategy should be developed and the technology be transferred to farmers.

Tilapia in Bangladesh and striped catfish in Viet Nam: perspectives on farming and FCR

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This paper reports the current status of two aquaculture industries in Asia, which have grown very rapidly in recent years. They have had rather different histories and target different markets, but their magnitude of production makes it important to see how improvements can be made.

Bangladesh imported Nile tilapia (Oreochromis niloticus) in the 1970's, and growth of production has accelerated recently. Farm-made feeds were used exclusively in the beginning, but the establishment of commercial feed mills in the country has changed that. From a recent survey, most farms use commercial feeds to some extent and the trend would appear to be moving towards exclusive use of commercial feeds. A wide range of production outcomes is found between farms, depending on many factors. Farm average FCR ranges from 1.25 to 1.90 for fish raised to harvest weights ranging from 180 to 750 g.

By comparison, Vietnamese production of striped catfish is now based entirely on commercial feeds. This has reduced the variation in FCR to farm averages of 1.65 to 1.79. However, with large water quality variations and average farm mortalities ranging from 10 to 25 percent, further improvements can be made.

Despite increased commercialisation of the industries, there are still many variations in production performance between farms in the different systems. Dissemination of good information to farmers will help to reduce these variations, standardise performance and then improve it.

Greenhouse gas emissions from Indian major carp farming in India

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India is the second largest producer of freshwater fish next to China. More than 80 per cent of the freshwater fish produced in India is constituted by

carps, mainly Indian major carps like catla and rohu. The present study was undertaken to examine the greenhouse gas emissions from carp farming in India to understand where and how GHG emission arise. Primary data were collected during the period from May to September 2015, from 6 feed mills and 12 farms using structured questionnaires. The farms surveyed were all in Andhra Pradesh, a major state for major carp production, and thus represent the production and marketing practices of Indian major carps. The farms stocked a mixture of rohu (90 percent) and catla (10 percent), the grow-out time ranged from 180 to 300 days, depending on stocking and harvest sizes. Manures and fertilisers were used by all farms to enhance natural food production in the water. All farms used commercial feeds, with some also making their own feeds. The feeds were mainly extruded feeds (floating pellets), although two farms reported using steam pressed pellets (sinking). The rohu were harvested at around 1 to 2 kg and the catla up to about 3 kg – both destined for domestic markets. At harvest, the fish were packed in ice, moved a short distance (10 – 100 km) by truck (10 to 17 tonnes) to assembling centres (10 – 30 km distance), repacked and were sent to the large markets (1 100 to 1 425 km) in 17 – 21 tonnes trucks and were sold whole.

A total of 18 raw materials were used by the 6 feed mills surveyed. All raw materials were sourced within India, except for one feed mill which used a 50 percent inclusion of a premix of raw materials from Indonesia. Animal protein sources were used at very low levels by four of the mills, soybean meal was the major protein provider, with other plant protein sources ranging from 5 to 10 percent, up to 15 percent for rapeseed meal. Rice bran and de-oiled rice bran were important ingredients. Maize and broken rice were the main providers of carbohydrates. Feeds contained a higher oil content in the feed than declared.

Greenhouse gas emissions from carp farming, encompassing production and transport of raw materials used for feed manufacture, energy used in production and transport of feed, on farm energy and on-farm emissions and post farm emission due to transport of fish, were estimated using an excel based aquaculture LCA model v.1.1. The emissions arising from cradle to farm gate was estimated to be 1 840 gCO_2e, of which the feed production emission intensity (no LUC) was 794 gCO_2e/kg LW (live weight). The emission intensity (EI) from feed transport from point of production to feed mill was 60 gCO_2e/kg LW, feed mill energy use was 118 gCO_2e/kg LW, feed transportation from mill to farm accounted for 55 gCO_2e/kg LW, on farm energy use constituted 105 gCO_2e/kg LW, on-farm N_2O was 198 gCO_2e/kg LW, and due to embedded fertilizers and fingerlings were 57 gCO_2e/kg LW and 453 gCO_2e/kg LW, respectively. Further reasons for the GHG emissions from carp farming and the possible ways of mitigation were discussed.

Life cycle assessment of three freshwater fish species in Asia: implications on GHG emissions and FCR

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Aquaculture is a rapidly developing industry, providing food to large numbers of people around the world, but there is increasing interest in understanding the potential impact it is having on the environment. In particular, the GHG emissions related to aquaculture production have received focus recently.

This paper introduces a small study initiated by FAO to gain preliminary information on the likely GHG emissions intensity associated with three major aquaculture systems in Asia: Nile tilapia in Bangladesh, Indian major carps in India and striped catfish in Viet Nam. A limited survey of feed companies and farms was carried out in each country, based on questionnaires focussing on the foreseen major drivers of GHG emissions.

In this introductory paper, production data is presented from each country on feed and fish, as well as some information on where and how the fish are marketed after harvest. The range of production methods and outcomes observed in each country is highlighted as a major cause of variation, but also a potential for improved outcomes in the future. The following paper will specifically address the GHG emissions.

Quantifying GHG emissions in aquaculture and identifying mitigation opportunities

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A preliminary life-cycle analysis was undertaken of the greenhouse gas (GHG) emissions arising from the production of three species of farmed fish in Asia: Nile tilapia in Bangladesh, Indian major carps in India and striped catfish in Viet Nam. In order to perform the analysis an excel-based model of the three systems was developed. The model quantifies the emissions arising pre-farm (e.g. in the production of feed, fertiliser and energy), on-farm (from energy use and pond N_2O emissions) and post-farm from the transport of fish to the retail point. The model is essentially descriptive and static, with some capacity for varying a limited number of key parameters. Input data was derived from a combination of primary data from feed mill and fish farm surveys and secondary data from a range of sources (e.g. FeedPrint, SEAT project, Feedipedia). The emissions intensity ($kgCO_2e$/kg LW at the farm gate) was 1.58 for Nile tilapia in Bangladesh, 1.84 for Indian major carp in India and 1.37 for striped catfish in Viet Nam. The main sources of emissions were: production of crop feed materials, transportation of feed materials and compound feeds, energy use in feed mills, N_2O from ponds, and energy use on fish farms.

Many opportunities exist for reducing the EI of aquaculture; the challenge is to identify the most cost-effective measures for a particular species/system. Relatively simple models, such as the one developed in this project, can provide insights into the impact of mitigation measures.

A tool to assess GHG contribution in aquaculture: salmon and other species as cases studies

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A simple Excel spreadsheet tool has been developed to assess the GHG emissions from aquaculture systems at the farm level. Boundaries were established that limited the scope of the model upstream from the farm to feed production and delivery and downstream to processing activities. The impact of waste production and delivery of product were deemed too complicated for the first-generation model.

Data for the model was derived from published literature that describes the emissions attributable to feed and from publicly available databases for estimating energy emissions. The tool utilizes two sets of data, published databases and inputted data from the farm's own data collection. We have

used salmon as a case study as there is significantly more data available on feed emissions for salmon than for the other major aquaculture fish species, however the model has data enabling a variety of other species to be evaluated as well.

The output for this model is an estimate of on farm GHG emissions based upon: Emissions directly attributable to feed production; transportation emissions directly attributable to feed delivery to the farm; Emissions due to on farm energy consumption for daily operations; Emissions derived from processing activities.

The simplicity of the model makes it a tool that a farmer may use to evaluate changing scenarios of FCR, transport etc., enabling an understanding of how changes to practices on the farm may help to reduce carbon footprint.

As feed may represent up to 80 percent of all GHG emissions the accuracy of the tool depends, to a great extent, on the available information of GHG emission factors contained within the feed.

The role of FCR as a performance indicator

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Aquaculture as a food producing process needs inputs and resources, especially fed aquaculture that requires external inputs and energy. Feed conversion ratio (FCR) can be a good indicator of farming efficiency, economic and environmental performance.

The presentation discussed the methodology, indicators and results of an assessment of FCR performance of salmon farming in southern Chile during 2004.

The assessment used a multiple component scorecard to evaluate production efficiency (PEF), FCR, the environmental condition of farm sites, and the environmental image of the industry. One hypothesis tested in the assessment was that larger companies would perform better (in terms of per tonne of salmon production) than smaller farms.

Simple statistical analysis and more sophisticated multivariate regression models were used to evaluate the impacts of various factors on the FCR. The results suggested that the FCR increased with the number of feeders and production volume and decreased with feeding technology; and that the size of company have no significant impact on FCR.

The presentation noted that feed conversion ratio (FCR) can be a good indicator of farming efficiency, economic performance, and environmental performance, including nutrient losses and eutrophication potential, food waste, and green-house gas contribution.

As a useful indicator of environmental and economic performance, FCR can be used in benchmarking analysis, improved by taking into consideration of mortality (i.e. biological FCR), and applied to other farmed species.

Improving feeds and FCR: the perspective from salmon farming

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Feed conversion ratio is a measure of an animal efficiency in converting delivered feed into increases of the mass gained by the animal, in our case salmon. Specifically, FCR is the mass of the input divided by the output.

It is the most important efficiency indicator in the salmon industry, as it embodies the potential of the fish (genetics) and the feed, the feeding practices, environmental and farming conditions and fish health. It can be used as a biological descriptor (biological FCR) where in the mass balance exercise we include all outputs produced, i.e., gross harvest and mortality biomass, or as a farming/economic efficiency indicator (economic FCR) where harvested biomass it is included as the sole output, excluding the mortality biomass. Large differences between the Economic and Biological FCR can be found in some farming cycles when disease outbreaks hit an operation. The emphasis of the talk will be in other aspects that influence feed conversion ratio, however, and how they have been approached by the salmon industry.

The salmon industry has become highly industrialized and high investment is required. The activity is concentrated principally in four countries; Norway, Chile, Scotland and Canada. In each of these countries salmon farming is an important contributor to the local economy. Important efforts in R&D have been made to improve productivity. Norway supports extensive R&D in public and private institutions through direct grants, tax incentives supported by the 0.3 percent levy on seafood exports. The high level of commitment to research and development has led to great innovations in different areas of the salmon industry such as genetics, feeding technology and feed with a positive impact in the feed conversion ratio.

Even with all the advances in knowledge, technology and materials, obtaining a good FCR at a farm level it is not an easy task. Increase in biomass is very closely related to the nutrient and energy intake. The challenge in aquaculture is to obtain a balance between maximum growth while losing a minimal

amount of feed. Feed intake is affected by environment, husbandry conditions, genetics and feed type. As well personnel overlooking the daily feeding must be trained, committed, skilled and experienced in order to secure a good feeding process. Finally, data registration and analysis will help understand the situation on each of the farming unit, with the correct interpretation of the indicators, actions can be taken to secure a better feed conversion ratio.

On reducing 'FCR' in semi-intensive Indian major carp culture in Andhra Pradesh, India

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The inland farmed aquaculture production of India in 2012 was 3 812 420 tonnes. Indian major carp culture is the main stay of Indian inland aquaculture. Andhra Pradesh, a southern coastal state is the leading aquaculture state in India. The most important freshwater aquaculture system in Andhra Pradesh is the semi-intensive pond culture of Indian major carps *Labeo rohita* (rohu), *Catla catla* (catla) and *Cirrhinus cirrhosus* (mrigal).

This still water Indian major carp culture system is rohu dominant (with rohu comprising 85–90 percent of the stocking density) with supplementary feeding and also use of fertilizers. The natural food, mainly phytoplankton and zooplankton, plays an important role in the overall nutrition of the fish, thus contributing significantly to food conversion ratio (FCR). Average production is 9 000 kg/ha/year. Mash feed, mainly comprising de-oiled rice bran, ground nut oil cake and cotton seed cake, is the most widely used type of supplementary feed. A significant number of farmers use sinking pelleted feed mixed with mash feed, either for the entire production period or for part of it. A very limited number of farmers use floating pelleted feed. The percentage of feed cost to total production cost ranged from 48 to 54 percent, in 2010.

The pelleted feed companies suggest standard feeding rates to different sizes of pond cultured Indian major carps grown up to market size.

Farmers have been following certain methods and strategies developed through their experience in the hope of reducing 'FCR'. Areas for further research and key impact factors to reduce 'FCR' have been identified. Most important of these are: estimating relative contribution of natural and supplementary feed to fish growth and 'FCR'; determining the relative economic efficiency of mash feed, sinking and floating pelleted feed; level of plasticity of natural food and supplementary feed consumption among the three Indian major carps, particularly between rohu and catla; impact of serious infectious diseases like Argulosis, bacterial haemorrhagic septicaemia, and also that of sudden pond de-stratification due to weather changes and

toxic phytoplankton like *Microcystis*. Research on Green House Gas (GHG) emissions and other foot prints of semi-intensive Indian major carp culture in the state is at a very early stage.

In this introductory paper, production data is presented from each country on feed and fish, as well as some information on where and how the fish are marketed after harvest. The range of production methods and outcomes observed in each country is highlighted as a major cause of variation, but also a potential for improved outcomes in the future.

History of FCR reduction in marine shrimp and its impact in shrimp farming in Ecuador

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Commercial shrimp farming in Ecuador began casually in 1967 around Santa Rosa, in the southern coastal region of the country. In these initial stages, ponds were filled naturally during high tides and after 5–6 months farmers harvested around 350 kilograms per hectare (kg/ha) of a mixture of the native shrimp species, ***Litopenaeus vannamei*** and *Penaeus stylirotris*. The culture was quickly expanded to all coastal provinces of Ecuador, placing the country as the world's top shrimp producer during the 80s, being surpassed in the early 90s by Thailand, China and other Asian countries. Today, it is estimated that Ecuador has about 213 000 hectares of shrimp farms and should export more than 350,000 metric tonnes in 2016.

On average, Ecuadorian shrimp farmers stock 8–15 larvae per square meter, implementing a low-density system that helps reduce the spread of diseases and maintain good environmental conditions. Over the past 10–15 years, local breeding programs helped achieve greater survival (around 45 percent in 1998 versus 60–75 percent in 2015) thanks to better disease resistance and produce larvae that exhibit a higher growth rate (0.7–0.9 g/week in 1999 versus 1.4–1.8 g/week in 2015). At the same time, feed manufacturers improved the quality of their products, successfully reducing the amount of fishmeal used and increasing feed digestibility and stability. An indicator of these improvements is the observed reduction in the feed conversion ratio (FCR), from 1.8–2.0 in 1998 to 1.2–1.6 in 2015. These developments were accompanied by the widespread use of probiotics during shrimp larviculture, nursery and grow-out phases. The combination of these different factors has allowed a sustainable increase in production levels, maintaining a semi-intensive low-density system in equilibrium with nature. The average yield per year increased from 275 kilograms per hectare in 2 000 and 2001, to 1 200 kilograms in 2013 and 2 000 kilograms in 2015.

Feed represents between 45 and 60 percent of production costs at the farm level and, according to a preliminary study realized in 2012–2013, around 50 percent of the greenhouse gas emissions of small shrimp farmers (<20 hectares' farms) in Manabi and Esmeraldas provinces. Feed is generally broadcasted manually over the entire pond area and the daily ration calculated based on weekly biomass estimates and pre-established feeding tables. Some farmers adjust feeding rates with the use of feed trays and/or stomach content checks. The maximum feeding rate is around 30 kg/ha per day, applied in one or two rations, obtaining FCRs that vary between 0.8 and 1.6 (national average is ±1.4).

A new feeding technology, adapted from salmon farming and based on sounds emitted by the shrimp while eating, is providing interesting information on shrimp feeding behaviour, reinforcing some findings that are already known and published for some time in the scientific literature, but not always applied at the farm (being for practical reasons, the high associated costs, or the lack of monitoring to adapt changes). Results provided so far by the "AQ1 Systems" indicate that: (1) shrimp are not fed enough in the Ecuadorian low-density ponds; (2) environmental changes will impact shrimp feeding activity (i.e., moulting; rain events; low oxygen concentrations); (3) shrimp seem to feed all day long and present a small increase in activity at night (between 6:00 pm and 8:00–9:00 pm); (4) there is a strong correlation between shrimp feeding activity and water temperature. After the diffusion of these results in local conferences, the Ecuadorian shrimp farmers were quick to implement changes in their production protocols, looking to improve their efficiency and reduce their production costs.

Management of FCR: the perspective from the shrimp Industry

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As we take on an increasing role of feeding our population through aquaculture, we most focus on the responsible and sustainable growth of our efforts. Managing our FCR (Feed Conversion Ratio) remains largely a frustrating and non-optimized exercise that shows great variability. When observing the advancements attained with terrestrial species, we find ourselves in the shrimp farming industry wanting similar models and significant control over limiting factors. Upon reviewing these limiting factors, we find that issues are common to other species in aquaculture. While acceptable common procedures in shrimp feeding and husbandry have been widely implemented and in use, much room for improvement remains in the areas of genetics, diet, infrastructure and husbandry. As we advance, the improvements will yield not only a lower carbon footprint but also a sustained lower cost of production.

Potential for reducing FCRs in in the farming of native tilapias in Malawi

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Aquaculture in Malawi is based on the farming of native tilapias (*Oreochromis shiranus* and *Tilapia rendalli*) in extensive, semi-intensive integrated ponds, cages and intensive recirculating aquaculture systems. Driven by low supply of tilapias and high prices (USD5/kg in 2015) Malawi's aquaculture production has increased almost ten-fold from 500 tonnes in 2 000 to 4 700 tonnes 2014, largely due to expansion of small-scale aquaculture and development of new commercial pond based and intensive recirculating aquaculture systems. Unable to close the tilapia supply gap estimated at 23,000 tonnes, supplied by the current capture and farmed tilapia production, Malawi has turned to farmed tilapia imports from neighbouring countries. The native tilapias, that are generally genetically unimproved and hence have slow growth rates (SGR = 0.3 to 0.6 percent/day), are farmed in extensive systems using agricultural by- products (maize bran, rice bran and occasionally soya meal) and extruded sinking feed made from maize, de-fatted soya and imported fish meal. Approximately 10 000 tonnes of feed, of which about 2 000 tonnes is formulated feed, is used annually in Malawi. Feed conversion ratios (FCRs) are high and typically range from 2 to 4 in small manured and fed ponds and 1.8 to 2.4 in large commercial ponds and cages. Improved feed management using web-based dynamic feeding regimes where daily feeding rate is determined by dissolved oxygen, water temperature and water levels, have been shown to reduce FCRs by 50 percent from 3 to 1.3 and increase yields from 3 to 7 tonnes/ha in semi-intensive commercial aquaculture ponds. The successful reduction in FCRs is also underpinned by adherence to best management practices that include grading of fingerlings prior to stocking at optimal densities, emergency aeration and control of predation. Due to increased aquaculture investments to meet growing local demand and increased adoption awareness by small and medium aquaculture enterprises use of extruded formulated feeds is projected to increase 3 to 5 times in the next 5 years that will benefit from improved feed formulation to suit the native Malawi tilapias. The success of web-based dynamic feeding systems under commercial conditions also suggest that use of mobile apps as a feed management advisory service would be critical to national-wide improvement of FCRs in Malawian small and medium scale fish farms

Application, interpretation and reduction of FCRs and consequences for major feed ingredients

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Economic sustainability of aquaculture is pivotal if we are to meet the increasing global demands for aquatic products. This in turn is predominantly dictated by significant operational costs of fish production. In the case of semi-intensive and intensive fish production feed cost, which accounts for 50–80 percent of production costs, is the determining factor. Hence, any efforts to minimize feed costs will greatly enhance sustainability and secure fish supplies. Our ability to measure, track and monitor its efficient use is therefore critical. The feed conversion ratio (FCR) is a primary indicator widely used in the sector to monitor the efficiency of feed utilisation. One factor that affects feed cost is the use of fishmeal and fish oil, which are in short supply. Hence, their reduction will also help reduce feed cost.

This presentation, critically examines the FCR for various species groups in key farming regions and species groups to extract if, how and where FCR can be improved to reduce costs whilst increasing production. This assessment is based on tabulated data and figures from various FAO case studies and elsewhere.

The FCR reported for the major species groups varies with production system and type of feed used. In China, Philippines, Egypt, and Ghana, FCRs ranged from 1.4 to 1.7 when pelleted feed was used for tilapia production. With extruded diets FCRs of between 1.2–1.4 have been reported. Similarly, for catfish in Viet Nam an average FCR of 1.6 is reported for extruded feed. For tiger and whiteleg shrimps such values range from 1.2–1.4. For salmon, in Norway, Scotland, Americas and Oceania, where the farming is highly mechanised, FCRs range 1.2–1.4 using high quality extruded diets, values used as benchmarks in this presentation. These reported FCRs are in fact economic feed conversion rations (eFCR) but could be used together with theoretical (tFCR) and biological FCR (bFCR) to estimate windows of opportunity for improving feed utilisation efficiency, assuming the tFCR to be 0.33 and best bFCR of around 0.6 – 0.7. On this basis the 50 percent, 63 percent, 70 percent and 79 percent of the eFCR for salmon (1.2), pangasius catfish (1.6), tilapias (1.7) and carps (1.8), respectively lies above the bFCR and provides a measure for the window of opportunity for improvement. Greatest improvement can be made in farming tilapias and carps where 70 percent and 79 percent of the eFCR lies above the bFCR of 0.6–0.7. The level of efficiency is a function of the dichotomy of production systems used for farming fish, industrialized fish farming, particularly of relatively high valued, mostly cold water cultured species such as the intensively farmed salmonids in large sea cages, versus small scale rural semi-intensive farms often clustered together. The interpretation of eFCR values from pond based farming is however difficult as these values are confounded by the effect of natural feed on harvest.

Many management factors are cited to influence feed utilisation. These include: nutritionally balanced feeds, increased digestibility, choice of pellet type, alternate higher and lower protein diets, mixed feeding schedules, timing of feeding, delay in onset of external feeding, feed administration, mortality and growth. Of these factors, mortality, even at low levels, probably has the biggest impact on eFCR as well as on wastage of fishmeal and fish oil resulting in significant financial losses. For example, in 2014 the Cermaq Group produced nearly 300 000 tonnes of salmonids and experienced an average mortality rate of 8 percent. This loss cost the company an estimated revenue loss of USD61 million and a wastage of some 15 000 tonnes of forage fish. If the cost of feed loss is included at 8 percent mortality, the overall cost to the company was USD71 million. For less sophisticated farming operations and smaller operators, mortality losses may be much higher. Based on FAO case studies for tilapia in Egypt, Thailand and Bangladesh mortalities could be as high as 30–60 percent.

At a global level, the wastage of fish from forage fisheries can be substantial. Based on 5 percent fishmeal inclusion in carp diets and 10 percent for tilapia and catfish, and 10 percent global mortality rate results in a total loss of about 1.5 million tonnes of forage fish. If global mortality is assumed to be 20 percent this loss increases to 6.4 million tonnes.

Unlike salmon farming in sea cages, oxygen levels in ponds are highly variable and significantly lower than in the sea cage environment, which can have a marked effect on feed utilisation efficiency. Studies on tilapia have shown when dissolved oxygen (DO) levels are above 7 mg/l, eFCRs of 1.5 could be achieved. However, if DO drops to 1–2 mg/l, the FCR can increase to over five. The use of aerators together with commercial feeds has resulted in eFCRs of 1.2–1.6 for tilapias in cages and ponds in Egypt and China.

Pellet type and stability can also affect feed utilisation efficiency. Typically, poor pellet stability leads to greater wastage. In addition, such pellets are more easily damaged during packaging and handling along the production value chain leading to higher percentages of fines and hence wastage.

Overall, farmers have limited control on the quality of manufactured feeds. Notable reduction in costs and efficiencies however could be gained from on farm management of feeds and the rearing environment. Reduction in mortality is likely to have the most immediate positive impact on improving feed utilisation efficiency, followed by higher DO levels, more careful feeding methods and on on-site feed storage.

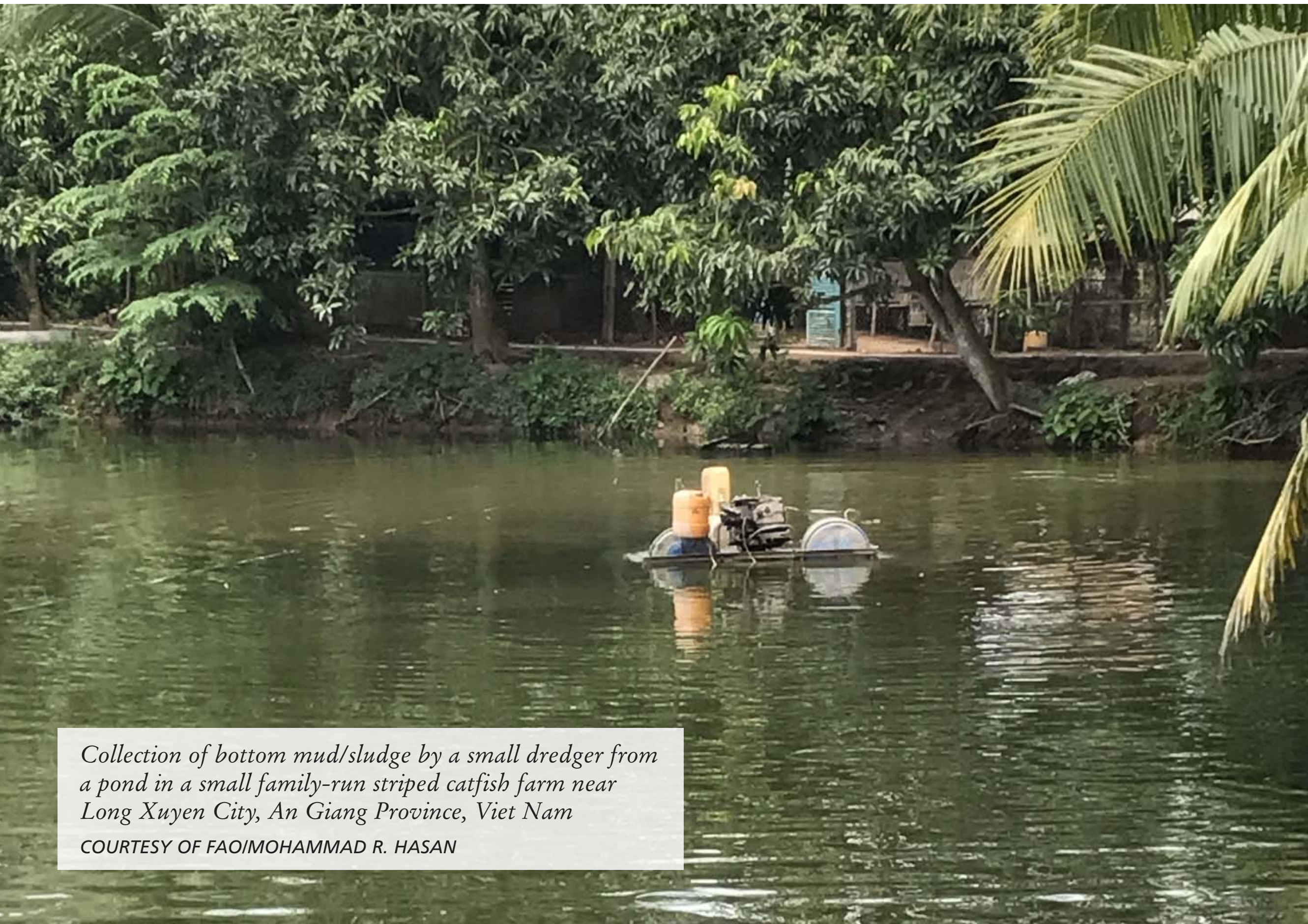
Section C: Workshop PowerPoint presentations

LIBERIA, COSTA RICA, 8–11TH NOVEMBER 2015

The PowerPoint presentations of the workshop are available at and can be downloaded from the following link:

http://www.fao.org/fileadmin/user_upload/affris/docs/FAO-GSI_Joint_Workshop_Presentations.pdf

Feeding of striped catfish with extruded floating feed from a floating raft in Mekong Delta, Viet Nam
COURTESY OF FAO/T.P. NGUYEN



Collection of bottom mud/sludge by a small dredger from a pond in a small family-run striped catfish farm near Long Xuyen City, An Giang Province, Viet Nam
COURTESY OF FAO/MOHAMMAD R. HASAN

Section D: FISH-e: FAO's tool for quantifying the greenhouse gas emissions arising from aquaculture

The GHG tool (**FISH-e**: FAO's tool for quantifying the greenhouse gas emissions arising from aquaculture) is available at the following link:

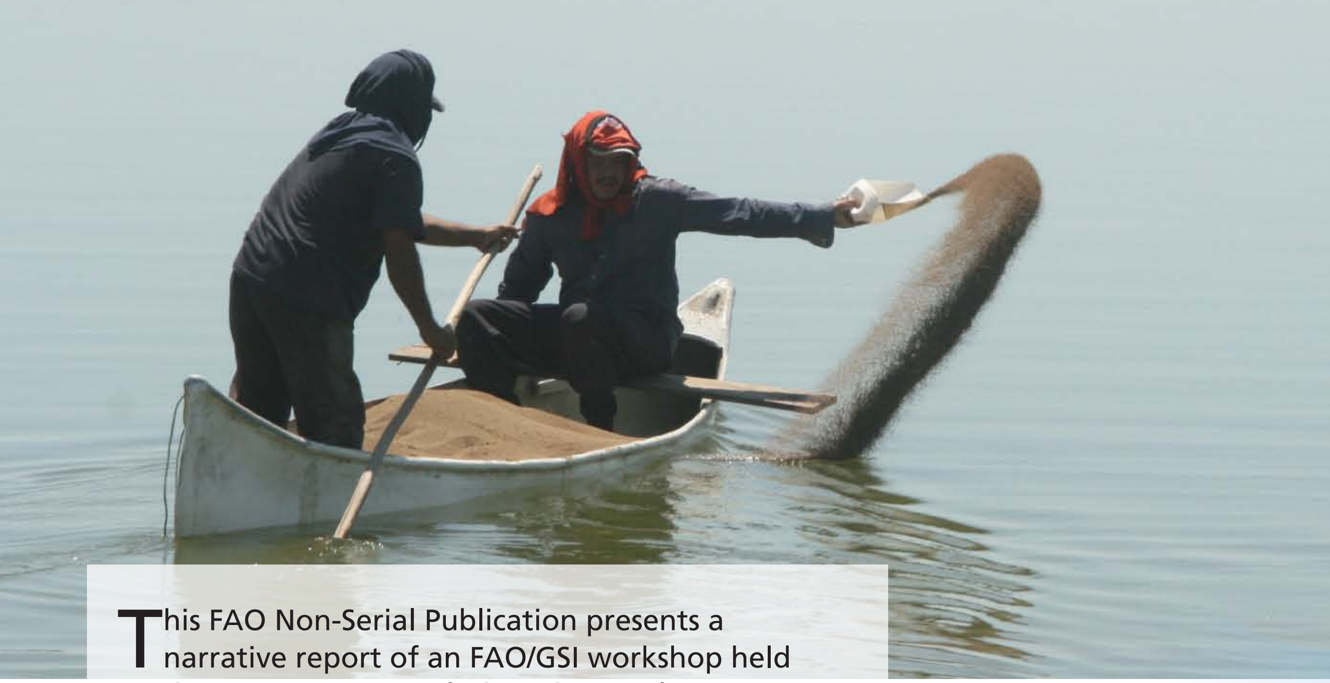
www.fao.org/fishery/affris/affris-home/fish-e-faos-tool-for-quantifying-the-greenhouse-gas-emissions-arising-from-aquaculture/en/

To reduce greenhouse gas emissions (GHGs) there is a need to understand how and why they arise. In meeting this challenge, FAO has developed a user-friendly tool that quantifies aquaculture greenhouse gas emissions. The tool is called FISH-emissions (or FISH-e for short).

It calculates the emission intensity (in kg of GHG per kg of live weight) for the main aquaculture commodities, including catfish, cyprinids, Indian major carps, salmonids, shrimps and tilapias. Users can change key parameters, such as species, location, ration composition and feed conversion ratio, and on-farm energy and fertilizer use; and explore how these influences the emissions intensity.

The emissions intensity of fish farming is intimately linked to the mix of feed materials in the ration, and of course, the efficiency with which these are then converted to live weight gain. Default rations are included in FISH-e for the most common aquaculture commodity/location combinations. In order for a more accurate calculation of emissions intensity, however, users can also enter specific ration compositions. They can also specify their energy and fertilizer consumption, which can also be important sources of GHGs in some systems. Once the information is entered, FISH-e calculates the emission intensity (or carbon footprint) and provides a graphical breakdown of the emissions by source, thereby enabling users to quickly identify the main sources of GHGs in their system.

Having identified the sources of emissions, farmers will then be able to target specific actions at their farms, that can contribute to a reduction in GHG emissions. Combined with the conclusions and outputs from the workshop in Liberia, Costa Rica, Governments, feed suppliers, farmers, and research and development organizations will be able implement strategies that aim to improve the overall sustainability of aquaculture production globally.



This FAO Non-Serial Publication presents a narrative report of an FAO/GSI workshop held in Liberia, Costa Rica including the conclusion and recommendations, summaries of technical presentation given at the workshop, a compendium of the PowerPoint presentations made in workshop, and an excel-based greenhouse gas tool for quantifying greenhouse gas emissions arising from aquaculture. The rationale of this study undertaken was to i) assess the current GHG contributions of aquaculture, related to feeds and feeding, and understand ways to measure it; ii) explore current potential for reducing feed conversion ratio (FCR) for a range of important and commercially significant species, and therefore continuing to improve their environmental performance including reductions in GHG and iii) explore potential transfer of feed and feeding technologies and lessons learnt from the well-developed salmon farming industry to other freshwater and marine species such as carps, catfishes, tilapia and shrimps. The findings of this study identified several factors that impact FCRs, particularly in species farmed in developing countries, which could be targeted with programs that ultimately would reduce GHG and other emissions. The study concluded that managing environmental aspects, simplifying farm management through improved farm monitoring systems, and improving feed management, would improve FCRs and reduce GHG emissions.

ISBN 978-92-5-109886-8

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I7688EN/1/08.17