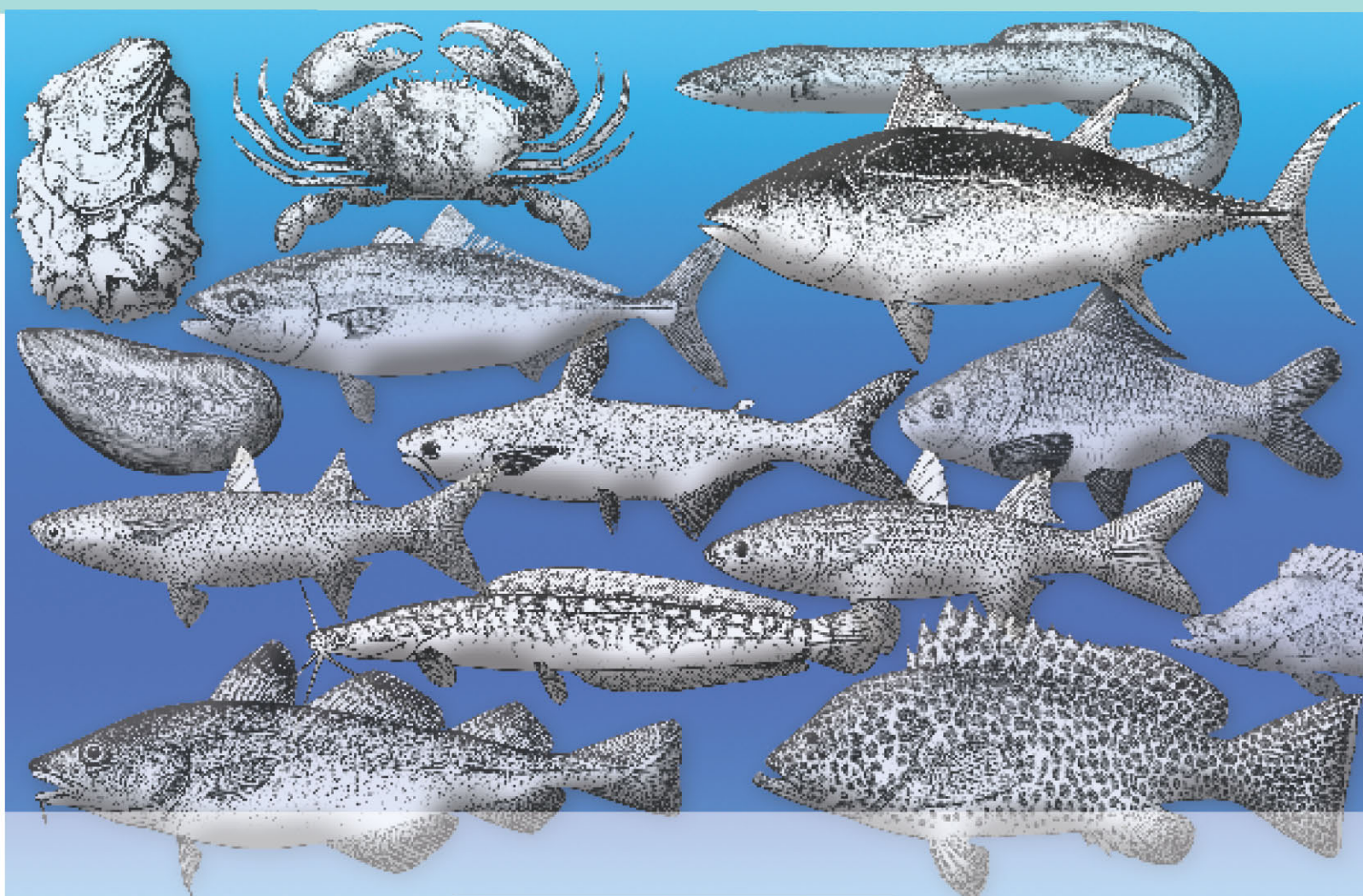


Capture-based aquaculture

Global overview



Cover:

Line drawings of commercial aquatic species produced through capture-based aquaculture. Drawings from the FAO Species Identification and Data Programme (SIDP). Montage created by Alessandro Lovatelli and José Luis Castilla Civit.

Capture-based aquaculture

Global overview

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Preparation of this document

The two thematic reviews on the (a) environmental and biodiversity and (b) socio-economic issues related to capture-based aquaculture and the eleven species-specific papers covering both marine and freshwater examples contained in this document have been prepared as support material for the “FAO international workshop on technical guidelines for the responsible use of wild fish and fishery resources for capture-based aquaculture production”. The workshop organized by the Food and Agriculture Organization of the United Nations (FAO) was held in Hanoi, Viet Nam, from 8 to 12 October 2007, with the collaboration of the Ministry of Agriculture and Rural Development (MARD).

The commissioning of the papers and presentation at the Hanoi workshop were organized by the Aquaculture Management and Conservation Service (FIMA) of the FAO Fisheries and Aquaculture Department and financially supported by the regular programme and extrabudgetary funds from the Government of Japan in support of the project “Towards sustainable aquaculture: selected issues and guidelines”.

Part 1 of the publication consists of two thematic reviews: “Environmental and biodiversity impacts of capture-based aquaculture” by Yvonne Sadovy and Min Liu of the University of Hong Kong and “Social and economic impacts of capture-based aquaculture” by Robert Pomeroy of the University of Connecticut-Avery Point. Part 2 reproduces the eleven species-specific papers prepared, in alphabetical order, by Choi Kwang Sik (oyster) of the Cheju National University (Republic of Korea); Makoto Nakada (yellowtail) of the Tokyo University of Marine Science and Technology (Japan); Thomas Nielsen (consultant) and Patrick Prouzet (European eel) of the Institut français de recherche pour l’exploitation de la mer (France); Bjørg H. Nøstvold, Kjell Ø. Midling, Bent M. Dreyer and Øystein Hermansen (cod) of the Norwegian Institute of Fisheries and Aquaculture Research (Norway); Francesca Ottolenghi (bluefin tuna) of Halieus (Italy); Anders Poulsen, Don Griffiths, So Nam and Nguyen Thanh Tung (Pangasiid catfish and snakehead) respectively of the Ministry of Agriculture and Rural Development (Viet Nam) (first two authors), Inland Fisheries Research and Development Institute (Cambodia) and Southern Sub-Institute of Fisheries Planning (Viet Nam); Victor Pouomogne (*Clarias* catfish) of the Institute of Agricultural Research for Development (Cameroon); Mhd Mokhlesur Rahman (Indian major carps) of the Center for Natural Resource Studies (Bangladesh); Magdy Saleh (mulletts) of the General Authority for Fish Resources Development (Egypt); Colin Shelley (mud crab) of YH & CC Shelley Pty Ltd (Australia); and Mark Tupper and Natasja Sheriff (grouper) of the WoldFish Center (Malaysia).

The photographs presented in the species papers were taken by the authors unless otherwise indicated.

The final revisions and inputs for the papers were provided by the technical editors, A. Lovatelli and P.F. Holthus.

Abstract

Aquaculture is a diverse and multibillion dollar economic sector that uses various strategies for fish production. The harvesting of wild individuals from very early stages in the life cycle to large mature adults for on-growing under confined and controlled conditions is one of these strategies. This system, referred to as capture-based aquaculture, is practised throughout the world using a variety of marine and freshwater species with important environmental, social and economic implications. The need to evaluate the sustainability of this farming practice in light of its economic viability, the wise use of natural resources and socio-environmental impacts as a whole has been extensively discussed at national, regional and international levels.

In 2004, the Food and Agriculture Organization of the United Nations (FAO) launched a project entitled “Towards sustainable aquaculture – selected issues and guidelines” funded by the Government of Japan which included a thematic component on the use of wild fish and fishery resources for aquaculture production. The objective is to produce a set of technical guidelines that would assist policy-makers in developing informed and appropriate capture-based aquaculture regulations that would take into account the use and conservation of the aquatic resources exploited.

This publication contains technical information prepared in support of and background material for the “FAO international workshop on technical guidelines for the responsible use of wild fish and fishery resources for capture-based aquaculture production” held in Viet Nam in October 2007. The first draft of the technical guidelines on capture-based aquaculture was produced during this meeting. This publication contains two parts. Part 1 consists of two reviews on (a) environmental and biodiversity and (b) social and economic impacts of capture-based aquaculture and Part 2 consists of eleven species review papers. Both marine and freshwater examples have been reviewed and include finfish (mullet, bluefin tuna, European eel, cod, grouper, yellowtail, *Clarias* catfish, Indian major carps, and snakehead and Pangasiid catfish), crustaceans (mud crab) and molluscs (oyster).

Lovatelli, A.; Holthus, P.F. (eds)

Capture-based aquaculture. Global overview.

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A special thanks also goes to the Government of Viet Nam and in particular to Mr Vu Van Trieu and Ms Nguyen Trang Thi Nhung, International Cooperation Department, Ministry of Agriculture and Rural Development, for their support in the organization of the “FAO international workshop on technical guidelines for the responsible use of wild fish and fishery resources for capture-based aquaculture” at which the papers included in this document were presented and discussed in preparation of the technical guidelines on capture-based aquaculture.

The editors also wish to thank Mr Jia Jiansan, Mr Rohana Subasinghe, Mr Devin Bartley, Mr Matthias Halwart and Mr Mohammad Hasan of the Aquaculture Management and Conservation Service, FAO Fisheries and Aquaculture Department, for their technical advice and review of selected papers. Ms Tina Farmer, Ms Françoise Schatto and Ms Helen Nakouzi, FAO Fisheries and Aquaculture Department, also contributed towards the final production of this document. The graphic layout of this technical paper was prepared by Mr José Luis Castilla Civit.

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Abbreviations and acronyms

ACIAR	Australian Centre for International Agricultural Research
ADB	Asia Development Bank
AIT	Asian Institute of Technology
APEC	Asia-Pacific Economic Cooperation
APGN	Asia-Pacific Grouper Network
APO	Associate Professional Officer
BFAR	Bureau of Fisheries and Aquatic Resources (Philippines)
BFRSS	Bangladesh Fisheries Resources Survey Systems
BFT	Bluefin tuna
BNP	Bacillary Necrosis of <i>Pangasius</i>
BOBP	Bay of Bengal Programme
BOD	Biological Oxygen Demand
BWDB	Bangladesh Water Development Board
CBA	Capture-based aquaculture
CCRF	Code of Conduct for Responsible Fisheries
CIRAD	Centre de coopération en recherche agronomique pour le développement (Cameroon)
CITES	Convention on International Trade in Endangered Species
CNRS	Center for Natural Resource Studies (Bangladesh)
COD	Chemical oxygen demand
COFI	Committee on Fisheries
COPIFOPEM	Collectif des pisciculteurs intensifs de Fokoué et Penka Michel (Cameroon)
CPUE	Catch per unit effort
CSIRO	Commonwealth Scientific and Industrial Research Organization
DANIDA	Danish International Development Agency
DARD	Department of Agriculture and Rural Development
DFID	Department for International Development (United Kingdom of Great Britain and Northern Ireland)
DO	Dissolved oxygen
DOCA	Deoxycorticosterone acetate
DOF	Department of Fisheries
EC	European Commission
EELREP	Estimation of the reproduction capacity of European eel
EIA	Environmental impact assessment
EIFAC	European Inland Fisheries Advisory Commission
ELISA	Enzyme linked immunosorbent assay
ELP	Early Life-history phase
EU	European Union
FAL	Fisheries Act Law
FAO	Food and Agriculture Organization of the United Nations
FCA	Fishermen's cooperative association (Japan)
FCDI	Flood control drainage and irrigation
FCR	Food Conversion Ratio
FFRC	Freshwater Fisheries Research Center (Bangladesh)
FOB	Free on Board
FRSS	Fisheries Resource Survey System (Bangladesh)

FSMFs	Fish seed multiplication farms (Bangladesh)
FSPS	Fisheries Sector Programme Support
GEF	Global environment facility
GFCM	General Fisheries Commission for the Mediterranean
GIS	Geographical Information System
GSI	Gonad Somatic Index
HACCP	Hazard Analysis and Critical Control Points
HBA	Hatchery-based aquaculture
HCG	Human Chorionic Gonadotropin
HUFA	Highly Unsaturated Fatty Acids
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of High Seas
ICLARM	International Center for Living Aquatic Resources Management
IFAD	International Fund for Agricultural Development
IFREMER	Institut français de recherche pour l'exploitation de la mer
INDICANG	INDICateurs d'abondance et de colonisation sur l'ANGuille européenne <i>Anguilla anguilla</i>
IRAD	Institut de recherche agricole pour le développement (Cameroon)
ITCZM	Integrated Tropical Coastal Zone Management
IUCN	World Conservation Union
IUU	Illegal, unregulated and unreported fishing
JFA	Japanese Fisheries Agency
LHRH-A	Luteinizing Hormone Releasing Hormone Analogue
LRFF	Live Reef Food Fish
LRFT	Live Reef Fish Trade
MAC	Marine Aquarium Council
MARD	Ministry of Agriculture and Rural Development (Viet Nam)
MEDRAP	Mediterranean Regional Aquaculture Project
MINEPIA	Ministère de l'élevage, des pêches et des industries animales (Cameroon)
MINRESI	Ministère de la recherche scientifique et de l'innovation (Cameroon)
MPAs	Marine Protected Areas
MRC	Mekong River Commission
NACA	Network of Aquaculture Centres in Asia-Pacific
NGOs	Non-governmental Organizations
ODA	Overseas Development Agency (United Kingdom of Great Britain and Northern Ireland)
PBT	Pacific bluefin tuna
PCB	Polychlorinated biphenyls
PCSD	Palawan Council for Sustainable Development
PECOSUDE	Pêches côtières et estuariennes du sud de l'Europe
PEPISA	Pêcheurs et pisciculteurs de Santchou (Cameroon)
R&D	Research and Development
RAP	Regional Office for Asia and the Pacific (FAO)
RIA2	Research Institute for Aquaculture No.2 (Viet Nam)
ROI	Return on investment
SAPB	Shrimp Action Plan for Bangladesh
SAR	Special Administrative Region
SARS	Severe Acute Respiratory Syndrome
SBT	Southern bluefin tuna
SCRS	Standing Committee on Research and Statistics (ICCAT)
SEAFDEC	South East Asian Fisheries Development Center

SL	Standard Length
SPC	Secretariat of the Pacific Community
SPREP	South Pacific Regional Environment Programme
SSB	Spawning Stock Biomass
STECF	Scientific, Technical and Economic Committee for Fisheries
SUDA	Sustainable Development of Aquaculture
TAC	Total allowable catch
TAFA	Tasmanian Fisheries and Aquaculture
TBT	Tributyltin
TL	Tail Length
TNC	The Nature Conservancy
UN	United Nations
UNDP	United Nations Development Programme
USAID	United States Agency for International Development
VHS	Viral Haemorrhagic Septicaemia
WFC	WorldFish Center (ex-ICLARM)

Introduction

Global production from aquaculture has grown substantially, contributing increasingly significant quantities to the world's supply of fish for human consumption. This increasing trend is projected to continue in forthcoming decades. It is envisaged that the sector will contribute more effectively to food security, poverty reduction and economic development by producing – with minimum impact on the environment and maximum benefit to society – 83 million tonnes of aquatic food by 2030; an increase of 37.5 million tonnes above the 2004 level.

Aquaculture is a diverse sector using many strategies for fish production. The harvesting of wild individuals, either as broodstock whose eggs will hatch and develop under culture in ponds or cages, or as early life-history stages for on-growing under confined and controlled conditions is one of these strategies. This system of aquaculture production has been termed by the Food and Agriculture Organization of the United Nations (FAO) as *capture-based aquaculture* (CBA) and is practiced worldwide on a variety of marine and freshwater species, with important environmental, social and economic implications.

Capture-based aquaculture has certain advantages and disadvantages compared to aquaculture which controls the full breeding cycle of farmed species. The system does not rely on controlling the reproduction and breeding of farmed species. Thus, species of high market value or those that are readily available naturally can be farmed without the necessity to develop hatcheries or breeding programmes. The lack of domestication potential for wild-caught species is, however, a prime disadvantage as genetic improvement is not possible even in the long term.

This type of aquaculture is practiced on high value marine finfish species such as tuna which require high protein diets and sturdy culture facilities. However, it is also used on low-value fish species that are sometimes farmed in small ponds or inexpensive farming systems with minimum inputs. The former provides economic opportunity, but requires substantial infrastructure and investment, whereas the latter provides food security and an additional income source to rural communities. All forms of CBA need to be evaluated in light of economic viability, the wise use of natural resources and the environmental impact as a whole.

The extent and scale of CBA practices are difficult to quantify, however it is estimated that they comprise about 20 percent of marine aquaculture production, with an annual market value of US\$1.7 billion. The culture of many freshwater species also relies partly or fully on fry caught from the wild because the supply from hatcheries is not adequate to meet the demand, or because the quality of hatchery-produced seed is perceived by farmers to be inferior to wild-caught seed. The main concern related to CBA is whether the seed fishery has a negative impact on wild stocks of the targeted species as well as non-targeted species. Although there is generally little data on this issue, some countries have tried to ban or somewhat restrict such fisheries.

There are environmental concerns which need to be addressed regarding the harvesting of wild resources for CBA. Many fishery management regulations have minimum size limits for harvested species, and often there are restrictions on the harvest of spawning adults. The targeted individuals in wild-caught farming are early life history stages and adults ready to spawn which may not be adequately covered by existing legislation. The impacts on natural populations that are “targeted” for this type of aquaculture, and impacts on the associated non-targeted species and the surrounding ecosystem, need to be addressed to determine the sustainability of CBA.

These sustainability issues in aquaculture development have been recognized by many scientists, government experts, aquaculture producers and suppliers, traders of aquaculture products, and social and environmental advocacy or stakeholder groups. Numerous national as well as international and intergovernmental meetings have concluded that there is a significant need to address and resolve those issues which constrain the sustainable development of aquaculture at the local, national, regional and global levels.

FAO and the Committee on Fisheries (COFI) have repeatedly discussed aquaculture and the need for international collaboration for the promotion of its sustainable development, and its potential contribution to development in many rural areas. The 1999 FAO Ministerial Meeting as well as the first and second Sessions of the COFI Sub-Committee on Aquaculture also reiterated strongly the need for enhanced efforts by the international aquaculture community to work towards more sustainable and responsible aquaculture production practices.

The project "*Towards sustainable aquaculture – selected issues and guidelines*" implemented by the FAO and funded by the Government of Japan, through a Trust Fund arrangement, has provided the means to address selected key issues of sustainability in global aquaculture practices and development. With due recognition to the recommendations of the FAO Committee on Fisheries/Sub-Committee on Aquaculture during its first two sessions, the thematic area on the "*use of wild fish and fishery resources for aquaculture production*" has been identified as a priority for targeted action.

Furthermore, the project has focused on collating and synthesizing available information on the aforementioned and other thematic areas and based on the information analysed provided possible management regimes and options for targeted response measures in relation to the specific issue of concern including constraints and problems, and with due consideration of feasibility and affordability of possible implementation of identified measures. The outputs generated by the project will assist FAO Member countries in the promotion and implementation of the provisions of the Code of Conduct for Responsible Fisheries (CCRF).

The specific objective of the previously mentioned project sub-component is to contribute to improved and effective fish farming and conservation of natural aquatic populations at the global level, with minimum disruption to responsible fisheries and livelihoods through the successful implementation of ecosystem approaches in fisheries. In order to achieve such an objective the FAO organized an international workshop in Hanoi, Viet Nam, in October 2007, to initiate the production of a set of technical guidelines on the responsible use of wild fish and fisheries resources for aquaculture production (see Annexes for workshop agenda, list of participants, expert profiles and group photograph). These technical guidelines, once available, aim at assisting policy-makers in developing policies and regulations that take account of both the use and conservation of aquatic resources.

In preparation of the Hanoi workshop, two main thematic reviews were prepared covering environmental and biodiversity and socio-economic issues related to CBA along with eleven species specific review papers that covered both marine and freshwater examples from around the world and the ecological, socio-economic and livelihood impacts associated with CBA. The commercial species and related geographical coverage included: mullet (Egypt); bluefin tuna (Europe); European eel (France/Europe); cod (Norway); mud crab (Asia-Pacific); grouper (Southeast Asia); yellowtail (Japan); snakehead and pangasiid catfish (Mekong region); Indian major carps (Bangladesh); *Clarias* catfish (Cameroon); and oyster (Republic of Korea). The two thematic reviews and species papers are included in this FAO Fisheries Technical Paper.

PART 1

REVIEW PAPERS

Environmental and biodiversity impacts of capture-based aquaculture

YVONNE SADOVY DE MITCHESON AND MIN LIU

Social and economic impacts of capture-based aquaculture

ROBERT POMEROY

Environmental and biodiversity impacts of capture-based aquaculture

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SUMMARY

The project “*Towards sustainable aquaculture: selected issues and guidelines*”, implemented by the Food and Agriculture Organization of the United Nations (FAO), seeks to address selected key issues of sustainability in relation to current global aquaculture practices and developments. The specific thematic area, *use of wild fish and fishery resources for aquaculture production*, is identified, an important component of which is aquaculture production systems based on *capture-based aquaculture* (CBA). Around this thematic area, two review papers, one covering social and economic aspects, the other environmental and biodiversity issues of wild resource use, and ten background papers on selected marine and freshwater species used for CBA, have been compiled.

The thematic review on environmental and biodiversity issues, reported on herein, covers a wide range of representative marine and freshwater, vertebrate and invertebrate species used for CBA, selected from the four major taxonomic groups of cultured organisms, molluscs, crustaceans, echinoderms and finfishes with the following objectives:

- to summarize the life history stage(s) and habitat(s) of seeds collected from the wild, the regions and countries where CBA is taking place, why and how they are being used, capture method(s) and volumes with associated bycatch and discards;
- to diagnose and discuss the current and/or potential impacts of CBA practice on the environment and wild stocks;
- to review current agreements and legislation for ensuring sustainability of wild seed fisheries and trade for CBA, methods to reduce bycatch and their implementation, and to discuss potential management measures at national and international levels;
- to discuss the fundamental relationships between life history stages being exploited and impacts on wild stocks; and
- to provide recommendations for sustainable wild seed and capture fisheries and CBA practices.

The review concludes that major representative species from the four different taxonomic groups share characteristics of high market demand, and high predictability in time or location leading to ease of capture and accessibility. Most CBA species are high value, luxury, species, rather than regular food fish or invertebrate species used for cheap daily consumption.

Although issues of disease, environment and biodiversity are also relevant to hatchery-based aquaculture (HBA), there are certain considerations specifically or indirectly pertinent to CBA practices and matters relevant to both CBA and HBA. With the extensive practice and development of CBA-related fisheries (seed fisheries), international transport and growing trade of wild seed both regionally and globally, problems of disease and genetic pollution associated with transfers and escapes of wild seeds may be a matter for concern. Moreover, the non-selective use of many gears associated with CBA, wasteful bycatch associated with the capture of certain species, high post-capture mortality of target species, and extensive use of fish feed (sourced from wild fish and hence a further pressure on wild populations) for grow-out, could mean that certain seed fisheries are not sustainable and have a negative impact on other fishery sectors of the same, or different, species.

Current and recent management measures, as well as those being developed that are applicable to various aspects of wild seed fisheries associated with CBA, are summarized and discussed. Management measures need to respond to problems noted in various fisheries, including declining catches, control of fishing gears, bycatch and damage to substrate. Wild seed fisheries for CBA are typically not managed or controlled effectively and most management measures are relatively recent, developed or adopted after the seed fishery has declined substantially.

CBA is an economic activity that is anticipated to expand in the short term, and is very likely to continue into the long term for many species. CBA is practised because it has become necessary or desirable as a livelihood, as an alternative means of controlling access to fishery resources, to meet market demand and, if practised properly, to enhance yield. It does not necessarily, as is often assumed, or even desirably, lead to HBA, does not demonstrably take pressure off wild stocks, and is typically practised with high value species, often for export or luxury markets, rather than inexpensive food alternatives for local use. Recommendations are provided that include the need to apply the precautionary principle, refer to the FAO Code of Conduct for Responsible Fisheries (CCRF), seek measures to reduce mortality of captured animals and to minimize bycatch of non-target species. For CBA activities, it is important to develop management approaches, especially where different life history phases of a stock are exploited by different fishing sectors, develop clear objectives and definitions in each case and consider culture practices that reduce dependence on carnivorous species and seek cheaper alternatives to provide affordable food for local use.

INTRODUCTION

Given growing shortages in many fishery resources, aquaculture is widely considered to be important for food provision and for reducing pressure on fisheries in both developing and industrialized countries. Aquaculture production has developed since the 1970s at an average annual increase rate of 8.8 percent with growth accelerating in recent years (FAO, 2007). Among the 200 or so species of mollusc, crustacean and finfish cultured, many are based on “grow-out” or “fattening” of wild-caught “seeds” (see “Definitions” below), the seeds ranging from very early in life to adults. In all cases these “seeds” are held for varying time in captivity and/or fed and/or protected from predators until they reach marketable size (FAO, 1997a, 2006; Ottolenghi *et al.*, 2004). This practice, the “growing-out” or “fattening” of wild-caught “seeds”, is referred to as “capture-based aquaculture” (CBA), and involves a range of marine and freshwater, vertebrate and invertebrate species. The fish production from such growing-out

or fattening practices is estimated to be at least 20 percent of the total annual fish aquaculture production with a value of US\$1.7 billion (FAO, 2004; Ottolenghi *et al.*, 2004). Although CBA has been practised for decades, it was not until 2004 that the descriptive term, CBA, was introduced to clearly define this practice and to distinguish it from hatchery-based aquaculture (HBA) on the one hand, and capture fisheries on the other hand (Ottolenghi *et al.*, 2004). In reality, CBA is a hybrid of these two practices but differs in important ways from both as a means of food production and in relation to fishing pressure on wild populations.

CBA has several widely assumed advantages resulting from its history and its apparent practical simplicity. For example, it is widely considered that the economic cost of seed taken directly from the wild is lower compared to seed reared in hatcheries for many species. It is also commonly believed that CBA is conducted on animals caught locally to culture operations and, therefore, that the risks of exotic disease transfer and genetic pollution to the environment and wild stocks are low to non-existent (Munro and Bell, 1997). These perspectives largely stem from the early practice of what has come to be known as CBA in some species of keeping alive in captivity animals taken in the local fishery to maintain them fresh for short periods of time until the market price improved or they were needed. Over time these practices expanded considerably to include trading of species both regionally (defined as within the geographical range of the species) and globally (defined as out of the geographical range of the species) or for extended maintenance in captivity for grow-out (Islam *et al.*, 1996; Mohan Joseph, 1998; Bagarinao, 1999; Jeffs *et al.*, 1999; Sadovy, 2000; Ottolenghi *et al.*, 2004).

One other factor that makes CBA appealing is the belief that taking fishes or invertebrates when they are small and young and placing them into captivity for feeding and protection from predators reduces their natural mortality. In this way, the practice is widely assumed to increase productivity by enhancing survivorship relative to natural levels at a given size or age. This may or may not be true and depends on many factors, most importantly on the life history stage(s) at which animals are removed from the wild and the volumes involved. While this subject is covered in more detail below, for those species in which natural mortality levels become very low within a few weeks or months of settlement, their capture before sexual maturation but after this early high natural mortality period could substantially affect the sustainability of natural populations. Moreover, the degree of bycatch and discards and the mortalities of wild seeds during and after capture (i.e. from capture and during culture) can be extremely high, factors rarely considered when examining the culture of such species. Combined, these factors mean that the costs, both economic and environmental/biodiversity, of CBA are substantially higher for some species than previously thought and the impacts of CBA on natural stocks generally not considered (Naylor *et al.*, 2000; Sadovy, 2000; Sadovy and Vincent, 2002; Ottolenghi *et al.*, 2004). Nonetheless, as demand for seafood grows and over-fishing and competition for fishery resources increase, CBA is inevitable and must be addressed directly to ensure sustainable practices especially when it is not considered, or has proven unlikely, to be a stepping stone to HBA.

As a combination of aquaculture and capture fisheries, CBA exhibits characteristics of both practices. For example, captive grow-out for CBA uses the same systems (e.g. extensive and intensive; ponds, cages and tanks), consumes the same natural resources (e.g. land, water and labour), and utilizes the same feeds (e.g. formulated/pellet feed or fresh feed that contain mainly small fishes and shellfish) as HBA. CBA also encounters some of the same problems, such as production of wastes and resultant contamination of the environment, diseases and their treatment and transfer. On the other hand, wild seed collection of many species for CBA has many similarities to typical capture fisheries, in terms of capture methods (including some that are destructive) and seasons, catch sizes, catch per unit effort (CPUE), bycatch

and discards, stock assessment and fishery management. In more extreme cases, CBA is little more than a capture fishery of juveniles, almost always unmanaged, and hence a clear and additional threat to the long term sustainability of targeted species.

CBA poses unique challenges to resource managers at a time when aquaculture is increasingly viewed as essential for future food production and for reducing over-fishing. The extent to which CBA contributes to both is, based on current practices for many species, far from clear. On the positive side, CBA is often a step towards HBA, a transition phase which allows much to be learned about rearing species before the challenges of hatchery production can be met. Conversely, some species used for CBA are also taken as part of traditional capture fisheries in fishing sectors that focus on adult fish, rather than seeds, and the removal of different life history stages by separate fishing sectors can lead to conflicts and problems of equity. Removing too many larvae and juveniles (i.e. immature individuals) for CBA, for example, could compromise stock persistence in the adult capture fishery sector because insufficient juveniles persist to maintain reproductive output, or *vice versa*. In addition, the option of CBA in over-fished stocks has resulted in the transfer of fishing effort from dwindling adults to juveniles possibly compromising stocks (Naylor *et al.*, 2000; Sadovy, 2000; Sadovy *et al.*, 2003; FAO, 2004; Ottolenghi *et al.*, 2004). In such cases, the apparent increased food production from CBA can come at the cost of reduced fishery captures leading to questions of equity and efficiency of use of limited fishery resources.

Notwithstanding concerns over CBA, it continues to be extensively practised despite limitations noted in the supply of wild seed in some cases and where there are no moves towards HBA. There are growing concerns, therefore, that the practice itself may be one more cause of reductions in seed availability and the adult fisheries that these support. Given these concerns and the ever-growing interest and focus on aquaculture in general, there has emerged a need for both developing and industrialized countries to create and implement a comprehensive framework of regulations and market mechanisms to ensure that the practice of CBA is conducted in a sustainable manner, and to understand more about CBA practices in general.

To achieve sustainable CBA there is a need for gathering data on the biology, practices and seed collection (seed fisheries) of CBA species. A wide range of representative marine and freshwater, vertebrate and invertebrate species used in CBA practices selected from four major groups, molluscs, crustaceans, echinoderms and finfishes are examined in this review. There are five objectives in relation to the selected species: (1) to summarize the life history stage(s) and habitat(s) of seeds collected from the wild, and the regions and countries where CBA is taking place and to indicate why and how they are being used; (2) to gather data on capture method(s), volumes, and associated bycatch and discards (when information is available); (3) to diagnose and discuss the current and/or potential impacts of CBA practices on the environment and wild stocks, based on the findings of (1) and (2); (4) to discuss current/recent and/or potential impacts in relation to transfer of wild-caught seeds in relation to diseases, genetic pollution, etc., providing examples, as appropriate; and (5) to review current agreements and legislation for ensuring sustainability of wild seed fisheries and trade for CBA, methods to reduce bycatch and their implementation, and to discuss potential management measures at national and international levels. The theoretical relationship between life history stages of certain species, their exploitation and its impacts on wild stocks, especially in relation to management decisions, are discussed. Finally, recommendations are given, based on information gathered in the present review for sustainable wild seed and capture fisheries and CBA practices.

DEFINITIONS

Aquaculture

The term is defined by FAO for statistical purposes (FAO, 1997b), “Aquaculture is the farming of aquatic organisms including fish, molluscs, crustaceans and aquatic plants. Farming implies some sort of intervention in the rearing process to enhance production, such as regular stocking, feeding, protection from predators, etc. Farming also implies individual or corporate ownership of the stock being cultivated. For statistical purposes, aquatic organisms which are harvested by an individual or corporate body which has owned them throughout their period contribute to aquaculture”. In this definition, the sources of the aquatic organisms farmed are not defined clearly; they can be either from the wild through capture and collection or from hatcheries through manipulation of broodstock maturation and reproduction, and larval and juvenile rearing.

Fisheries

“It is a practice of capturing aquatic organisms by the public as a common property resource, with or without appropriate licences” (FAO, 1997b). According to this definition, wild seed collection is a type of fisheries. The significant difference between capture fisheries and seed fisheries is that the caught aquatic organisms go to market directly in the former case, and to culture operations before entering markets in the latter.

Capture-based aquaculture (CBA)

It is a practice of collecting “seeds” (see below) from the wild from early life history stages to adults and subsequent growing-out them in captivity to marketable size, using aquaculture techniques (Ottolenghi *et al.*, 2004). This definition can clearly distinguish CBA from HBA, which is a practice of producing and using “seeds” from hatcheries through manipulation of adult maturation and reproduction and larval and juvenile rearing.

Seeds

“Seeds” are the aquatic organisms used to farm in captivity for varying times; these organisms can be captured and collected from the wild (e.g. for CBA) or hatched in hatcheries (e.g. for HBA). These organisms cover a wide range of life history stages, from larvae to juveniles to adults, defined on the basis of morphology, including size, and sexual maturation stage. Larvae are the stage prior to metamorphosis; they can be pre-settlement or early post-settlement and differ in form and appearance from the adults. Juveniles are the stage from after metamorphosis to prior to sexual maturation; they can be late post-settlement and are often similar in form and appearance to the adults. Adults are the stage after sexual maturation. Wild seeds collected for CBA are not only from early life history stages (larvae and juveniles) but also from adult stages depending on the species and market demands. We use “larvae”, “juveniles” or “adults” instead of “seeds” in this report whenever they can be distinguished clearly or where the distinction is relevant. Sub-adults refer to late stage juveniles that will soon reach sexual maturation.

Some words are also commonly used to describe early life history stages of aquatic organisms, such as “fry” and “fingerling”. “Fry” can be applied to larval stage in finfish, or post-larvae (i.e. after metamorphosis) in shrimps, and “fingerling” can be applied to small juveniles in finfish.

Grow-out and fattening

“Grow-out” in CBA is the process of farming the aquatic organisms captured and collected from the wild till they reach marketable size. The grow-out period varies

on the basis of the life history stages of the farmed organisms at the start and the market demand for each species and circumstance. If the organisms started from larval and small juvenile stages, they usually need to be kept in captivity for a considerably longer period to reach marketable size, unless there is sale between grow-out phases for economic reasons; if the organisms are at sub-marketable size (e.g. large juvenile and adult stages), they need relatively short period to reach marketable size. “Fattening” is a type of grow-out activity, which particularly focuses on sub-marketable or even marketable size individuals aiming to increase the fat content (e.g. tunas *Thunnus* spp.) or the gonad maturation (e.g. female mud crabs *Scylla* spp.) through a short culture period for a better price, usually accompanied with high feed input. The differences between “grow-out” and “fattening” are the relative length of the culture period, and the life history stage being cultured in some cases, although in practice the difference between the two is often unclear, such as “grow-out” of sub-adult grouper and “fattening” of sub-adult or adult tuna.

REPRESENTATIVE SPECIES IN CBA

Selected representative species for CBA from four taxonomic groups, molluscs, crustaceans, echinoderms and finfishes, are summarized, with a focus on understanding their life history stage(s) and habitat(s) captured and collected as seeds, the regions and countries where CBA is taking place (Tables 1 and 2). Four classes of species in CBA were identified according to market demand both locally and internationally, stock condition, high predictability in time and/or location, ease of capture and accessibility. Most are higher value species rather than regular food for cheap daily consumption because these are the species on which much of CBA is focused, so economic forces are also a major factor in determining which species are selected for CBA.

- Certain valuable species are taken at a wide range of life history stages, from larvae and juveniles of various sizes to adults. Highly valued species included are spiny lobsters (*Jasus* and *Panulirus* spp.), mud crabs, sea cucumbers (*Holothuria* and *Parastichopus* spp.), Atlantic cod (*Gadus morhua*), groupers (*Epinephelus* spp.), the humphead wrasse (*Cheilinus undulatus*) and tunas (*Thunnus* spp.). As adult stocks have become overexploited, attention has turned increasingly to gaining possession of these species at an earlier life history stage and raising them to marketable sizes.
- Among certain finfishes, such as eels (*Anguilla* spp.), milkfish (*Chanos chanos*), shark catfishes (*Pangasius* spp.), mullets (*Liza* and *Mugil* spp.), temperate basses (*Dicentrarchus* and *Lateolabrax* spp.), jacks (*Seriola* spp.), rabbitfishes (*Siganus* spp.) and tunas, their early life history stages (and to some extent the adult stage) collected for CBA are highly predictable in time and/or location. These species have aggregation, migration and/or shoaling behaviours, the routes, habitats and seasons of which are well-known. Aggregation or shoaling makes such species particularly vulnerable to over-fishing because large numbers can be caught very efficiently and often easily, becoming the basis of seasonal fisheries.
- The habitats of early life history stages of certain desirable species may be very well-known or distinctive and easy to access. For example, for most molluscs spats settle in intertidal or subtidal zones of coastal waters and are easily and readily collected on artificial settlement collectors or identifiable natural substrates. For crustaceans, such as spiny lobsters and mud crabs, pueruli and megalopa (i.e. larval stage) pre-settlement occurs in large numbers near estuaries, lagoons or mangrove areas. For freshwater catfishes (*Clarias* spp.) and snakeheads (*Channa* spp.), the early life history stages are readily found in swamps, shallow waters and marshes.

TABLE 1

Selected representative species of molluscs, crustaceans and echinoderms taken for CBA with a summary of the life history stage(s) and habitat(s) of wild seeds collected, and the regions and countries where CBA is taking place. *, see Definitions; **, not an exhaustive country list

Representative species	Life history stage(s) of wild seed collected*	Habitat(s) collected	CBA region/country**	References
MOLLUSCS				
Mytilidae (mussels)				
<i>Mytilus edulis</i>	Spats (juveniles) after settlement with <10 mm;	Hard substrate of intertidal and subtidal zones of shore waters	<i>Global</i> Asia: China, Korea Rep., Philippines, Singapore, Thailand Europe: Denmark, France, Italy, Netherlands, Spain <i>South America</i> North America Oceania: Australia, New Zealand	Lutz, 1980; Lovatelli, 1988a; Delmendo, 1989; Hickman, 1992; Chou and Lee, 1997; Mohan Joseph, 1998; Jeffs et al., 1999; TAFE, 1999-2004; Smaal and Lucas, 2000; Burton, MacMillan and Learmouth, 2001; Jia and Chen, 2001
<i>Mytilus galloprovincialis</i>	Sub-marketable size with <50 mm			
<i>Perna canaliculus</i>				
<i>Perna viridis</i>				
Pteriidae (pearl oysters)				
<i>Pinctada margaritifera</i>	Spats (juveniles) after settlement	Reef habitats with 25–40 m deep, clean and pollution-free seawaters	<i>Regional</i> Asia: Japan, Indonesia Oceania: Australia, Cook Islands, French Polynesia	Gervis and Sims, 1992; Ellis and Haws, 1999; Ponia et al., 2000; Tisdell and Poirine, 2000
<i>Pinctada maxima</i>				
Pectinidae (scallops)				
<i>Argopecten purpuratus</i>	Spats (juveniles) after settlement with about 3–10 mm	Sandy or muddy bottoms of shore waters with fine gravels or stones	<i>Global</i> Asia: Japan Europe: Russian Federation, United Kingdom North America: USA <i>South America</i> : Chile Oceania: Australia	Lovatelli, 1987; TAFE, 1999-2004; Burton, MacMillan and Learmouth, 2001; Ivin et al., 2006; Kosaka and Ito, 2006; Norman, Román and Strand, 2006; Parsons and Robinson, 2006; von Brand et al., 2006
<i>Chlamys opercularis</i>				
<i>Mizuhopecten yessoensis</i>				
<i>Patinopecten yessoensis</i>				
<i>Pecten maximus</i>				
<i>Placopecten magellanicus</i>				
Ostreidae (true oysters)				
<i>Crassostrea gigas</i>	Spats (juveniles) after settlement with 5–10 mm;	Estuaries waters, intertidal zones with sandy or muddy flats, or rocky substrates	<i>Regional</i> Asia: China, Japan, Korea Rep., Philippines, Thailand Europe: France, Ireland, Netherlands, Norway, Spain, Yugoslavia	Korringa, 1976a; Ling, 1977; Lovatelli, 1988a, b; Park et al., 1988; Delmendo, 1989; Smaal and Lucas, 2000; Burton, MacMillan and Learmouth, 2001
<i>Crassostrea plicatula</i>	Sub-marketable size			
<i>Crassostrea rivularis</i>				
<i>Crassostrea virginica</i>				
<i>Ostrea edulis</i>				
Cardiidae (cockles)				
<i>Anadara granosa</i>	Spats (juveniles) after settlement with 6–10 mm or 5–10 g	Intertidal zones with muddy or sandy bottoms	<i>Regional</i> Asia: China, Indonesia, Korea Rep., Malaysia, Philippines, Thailand, Viet Nam Europe: UK	Lovatelli, 1988a; Tiensongrusmee and Pontjoprawiro, 1988a; Delmendo, 1989; Burton, MacMillan and Learmouth, 2001; Minh, Yakupitiyage and Macintosh, 2001
<i>Cerastoderma edule</i>				

USA = United States of America

UK = United Kingdom

TABLE 1
Continued

Representative species	Life history stage(s) of wild seed collected*	Habitat(s) collected	CBA region/country**	References
CRUSTACEANS				
Penaeidae (shrimps) <i>Metapenaeus</i> spp. <i>Penaeus japonicus</i> <i>Penaeus monodon</i> <i>Penaeus vannamei</i>	Post-larvae (PL) (juveniles)	Surf zones, shore waters with sandy bottoms, estuaries areas, tidal canals, mangrove areas	<i>Regional</i> Asia: Bangladesh, India, Indonesia, Malaysia, Philippines, Viet Nam <i>South America</i> : Ecuador	Ling, 1977; Ungson, 1990; Phillips, Lin and Beveridge, 1993; Islam et al., 1996; De Silva, 1998; Naylor et al., 2000; Petersson, 2002; SAPB, 2002; Ottolenghi et al., 2004; M.L. Cobo personal communication, 2007
Palinuridae (spiny lobsters) <i>Jasus edwardsii</i> <i>Panulirus homarus</i> <i>Panulirus ornatus</i> <i>Panulirus polyphagus</i>	Pueruli (larvae) between 7–8 mm and 0.25–0.35 g, and 10–15 mm and 1–9 g, at settlement and post-settlement with age of 1–2; Juveniles up to 30–80g, 100–300g	Coastal waters near estuaries, bays, gulfs and lagoons and coral reefs with sandy or muddy bottoms	<i>Regional</i> Asia: India, Indonesia, Malaysia, Philippines, Singapore, Taiwan PC, Thailand, Viet Nam <i>Oceania</i> : Australia, New Zealand	Chou and Lee, 1997; TAFE, 1999–2004; Phillips et al., 2003; Arcenal, 2004; Bell, 2004; Junio-Memez and Gotanco, 2004; Thuy and Ngoc, 2004; Gardner et al., 2006
Portunidae (crabs) <i>Scylla olivacea</i> <i>Scylla paramamosain</i>	Megalopa (larvae); Juveniles; Sub-marketable sizes (water crabs) with <100 mm and <200 g	Tidal zones with muddy bottoms, seagrass beds and mangrove areas near estuaries and lagoons	<i>Regional</i> Asia: China, India, Indonesia, Japan, Malaysia, Philippines, Singapore, Taiwan PC, Thailand, Viet Nam	Ling, 1977; Angell, 1992; Chou and Lee, 1997; De Silva, 1998; Keenan and Blackshaw, 1999; Le Vay, 2001; Minh, Yakupitiyage and Macintosh, 2001
ECHINODERMS (sea cucumbers)				
Holothuriidae <i>Holothuria scabra</i> Stichopodidae <i>Parastichopus californicus</i>	Juveniles with >1 g; Sub-marketable sizes with about 100 mm	Coastal shallow waters with sandy bottoms, scattered rocks, gravels and seagrass	<i>Regional</i> Asia: Indonesia, Japan <i>North America</i> : Canada	Tiensongrusmee and Pontjoprawiro, 1988b; Tanaka, 1992; Conand and Tuwo, 1996; Sutherland, 1996; Lovatelli et al., 2004; Tuwo, 2004

Taiwan Province of China abbreviated as Taiwan PC.

TABLE 2

Selected representative finfishes taken for CBA with a summary of the life history stage(s) and habitat(s) of wild seeds collected, and the regions and countries where CBA is taking place. *, see Definitions; **, not an exhaustive country list. Classifications follow those of Nelson 2006 with species names accessed 2007 from <http://www.fishbase.org>

Representative species	Life history stage of wild seed collected*	Habitat collected	CBA region/country**	References
Anguillidae (freshwater eels) <i>Anguilla anguilla</i> <i>Anguilla australis</i> <i>Anguilla japonica</i> <i>Anguilla rostrata</i>	Larvae and elver eels (juveniles) with <100 mm during their migration from seas to gain access to rivers	Estuaries and coastal waters near river mouths	Global Asia: China, Japan, Korea Rep., Taiwan PC, Western Europe: France, Italy, Netherlands North America: USA Oceania: Australia	Korringa, 1976b; Ling, 1977; Tzeng, 1997; Ringuet, Muto and Raymarkers, 2002; Ottolenghi et al., 2004; Sugiyama, Staples and Funge-Smith, 2004
Chanidae (milkfishes) <i>Chanos chanos</i>	Larvae with 10–20 mm during their migration from open sea for foods and appear seasonally in large numbers	Surf zones and shore waters with sandy beaches, river mouths, wetlands, lagoons, estuaries and mangroves swamps	Regional Asia: Indonesia, Philippines, Taiwan PC Pacific Islands	Korringa, 1976b; Ling, 1977; Uwate et al., 1984; Bagarinao et al., 1986; Uwate, 1988; Hickman, 1989; Ungson, 1990; Pullin, 1993; Bagarinao, 1994, 1999; Ahmed et al., 2001; Ottolenghi et al., 2004; Rimmer, 2006
Clariidae (airbreathing catfishes) <i>Clarias batrachus</i> <i>Clarias macrocephalus</i>	Larvae and juveniles	Swamps, flooded lowlands	Regional Asia: Bangladesh, China, India, Indonesia, Malaysia, Philippines, Thailand	Ling, 1977; Tripathi, 1996
Pangasiidae (shark catfishes) <i>Pangasius bocourti</i> <i>Pangasius hypophthalmus</i>	Larvae with 13–20 mm during their migration back along down streams; Juveniles	Along Mekong River and its tributaries	Regional Asia: Cambodia, Thailand, Viet Nam	Ling, 1977; Edwards, Little and Yakupitiyage, 1997; Trong, Nguyen and Griffiths, 2002; Van Zalinge et al., 2002; Lieng and Hortle, 2005
Gadidae (cods) <i>Gadus morhua</i>	Juveniles with 3–10 g; Sub-marketable sizes with 1–2 kg	Around coastal waters	Regional Europe: Iceland, Norway	Björnsson, Hugason and Gunnarsson, 2005
Mugilidae (mulletts) <i>Liza ramada</i> <i>Mugil cephalus</i>	Larvae and juveniles with 20–100 mm during their migration from open sea for foods	Around coastal shallow waters with sandy or muddy bottoms, or dense vegetation, estuaries and lagoons	Global Asia: China, Hong Kong SAR, India, Indonesia, Israel, Korea Rep., Taiwan PC Africa: Egypt, Nigeria, South Africa, Tunisia Europe: Greece, Italy, Turkey Oceania: Hawaii, Guam	Korringa, 1976b; Major, 1978; MEDRAP/ TR, 1985; Costa-Pierce, 1987; Hickman, 1989; Allen, 1991; Chandrasekaran and Natarajan, 1993; Nlewadim and Deekae, 1997; De Silva, 1998; Sadek, 2000; Sadek and Mires, 2000; Tamaru et al., 2001
Moronidae (temperate basses) <i>Dicentrarchus labrax</i> <i>Lateolabrax japonicus</i>	Larvae and juveniles with >20 mm length with shoaling behaviour	Around coastal shallow waters with sandy or muddy bottom and dense vegetation, estuaries, lagoons, harbours, creeks	Global Asia: China, Israel Africa: Egypt Europe: France, Italy, Spain, Turkey	Pickett and Pawson, 1994; Zheng, 1994; Sadek, 2000; Sadek and Mires, 2000

TABLE 2
Continued

Representative species	Life history stage of wild seed collected*	Habitat collected	CBA region/country**	References
Serranidae (sea basses) <i>Cromileptes altivelis</i> <i>Epinephelus akaara</i> <i>Epinephelus awoara</i> <i>Epinephelus bleekeri</i> <i>Epinephelus coioides</i> <i>Epinephelus malabaricus</i> <i>Plectropomus leopardus</i>	Pre- and post-settlement stage larvae, juveniles and sub-marketable sizes with 10–250 mm and up to 200 g, most 20–100 mm	Coastal waters with seagrass beds, mangrove waters near river mouths and estuaries, lagoons, tidal pools and reef areas	<i>Global</i> <i>Asia:</i> China, Hong Kong SAR, Indonesia, Malaysia, Philippines, Saudi Arabia, Singapore, Sri Lanka, Taiwan PC, Thailand, Viet Nam <i>North America:</i> USA, Caribbean countries	Glude, 1982; Tseng, 1983; Heemstra and Randall, 1993; Chou and Lee, 1997; Tseng and Ho, 1988; Huang, 1998; Sadovy, 2000; Tuan, Nho and Hambrey, 2001; Ottolenghi et al., 2004; H.S. Wang personal communication, 2006
Carangidae (jacks and pompanos) <i>Seriola dumerili (purpurascens)</i> <i>Seriola lalandi</i> <i>Seriola quinqueradiata</i>	Larvae with about 12–15 mm and 2–10 g aggregating with floating fields of seaweeds prior to their pelagic life stage; Juveniles with 25–100 mm and 25–100 g	Coastal, oceanic and offshore waters with floating fields of seaweeds	<i>Global</i> <i>Asia:</i> China, Hong Kong SAR, Japan, Korea Rep., Taiwan PC, Viet Nam <i>Europe:</i> Italy, Spain <i>Oceania:</i> Australia	Korringa, 1976b; Wilson, 1997; Tuan, Nho and Hambrey, 2000; Ottolenghi et al., 2004
Lutjanidae (snappers) <i>Lutjanus argentimaculatus</i> <i>Lutjanus johni</i> <i>Lutjanus lineolatus</i> <i>Lutjanus russellii</i>	Juveniles	Not well-known: could be around coastal waters with seagrass beds, mangrove waters near river mouths and estuaries, lagoons, tidal pools and reef areas	<i>Regional</i> <i>Asia:</i> Hong Kong SAR, Malaysia, Singapore, Thailand, Viet Nam	Wilson, 1997; Chou and Lee, 1997; Huang, 1998
Sparidae (porgies) <i>Acanthopagrus (Sparus) latus</i> <i>Acanthopagrus schlegelii</i> (<i>Sparus macrocephalus</i>) <i>Pagrus (Pagrosomus) major</i> <i>Sparus aurata</i>	Larvae and juveniles with 20–100 mm and 0.2–10 g	Around coastal shallow waters with sandy or muddy bottoms and dense vegetation, estuaries and lagoons	<i>Global</i> <i>Asia:</i> China, Hong Kong SAR, Japan, Taiwan PC <i>Africa:</i> Egypt <i>Europe:</i> Turkey	Korringa, 1976b; Tseng, 1983; MEDRAP/TR, 1985; Wilson, 1997; Sadek, 2000; Sadek and Mires, 2000
Labridae (wrasses) <i>Cheilinus undulatus</i>	Juveniles and sub-marketable sizes with 200–400 mm and <300 g	Around lagoon reefs with seagrass beds, hard and soft corals, and mangrove areas	<i>Regional</i> <i>Asia:</i> Indonesia, Malaysia, Papua New Guinea, Philippines, Singapore	Chou and Lee, 1997; Huang, 1998; Sadovy et al., 2003
Siganidae (rabbitfishes) <i>Siganus canaliculatus</i> Other <i>Siganus</i> spp.	Juveniles with shoaling behaviour and predictable seasonality	Around coastal waters with seagrass beds, mangrove areas, and offshore	<i>Regional</i> <i>Asia:</i> China, Hong Kong SAR, Indonesia, Singapore, Taiwan PC <i>Oceania:</i> Fiji	Glude, 1982; Tseng, 1983; Uwate et al., 1984; Hickman, 1989; Chou and Lee, 1997
Scombridae (mackerels and tunas) <i>Thunnus maccoyii</i> <i>Thunnus thynnus</i>	Juveniles, sub-marketable sizes and adults with as small as 150–500 g, to 20–80 kg, to 80–120 kg, up to 600 kg and with shoaling behaviour	Oceanic and pelagic waters	<i>Global</i> <i>Asia:</i> Japan <i>Europe:</i> Croatia, Malta, Italy, Spain, Turkey <i>Africa:</i> Morocco, Tunisia <i>North America:</i> Canada, Mexico, USA <i>Oceania:</i> Australia	Ottolenghi et al., 2004; UNEP/MAP, 2004; Vita and Marin, 2007
Channidae (snakeheads) <i>Channa (Ophiocephalus) argus</i> <i>Channa micropeltes</i> <i>Channa striata</i>	Larvae and juveniles with 15–100 mm	Shallow waters of lakes, swamps, marshes	<i>Regional</i> <i>Asia:</i> Cambodia, China, Hong Kong SAR, India, Korea Rep., Laos, Malaysia, Philippines, Taiwan PC, Thailand, Viet Nam	Ling, 1977; Wee, 1981; Boonyaratpalin, McCoy and Chittapalpong, 1985; Edwards, Little and Yakupitiyage, 1997

- In many places, although CBA was originally a localized practice, the growing demand for seafood, declining wild stocks of some species, and improved means of international transport of live aquatic organisms, now mean that regional and global trade in wild-caught seeds is common, especially for finfishes. For example, Asian countries such as China and Japan import European glass and elver eels (*Anguilla anguilla*) to make up the short supply of the local species, Japanese eel (*Anguilla japonica*) in CBA (Ottolenghi *et al.*, 2004; J.B. Liu personal communication, 2007). For the shark catfish (*Pangasius hypophthalmus*), regional transfer (mainly from Cambodia to Viet Nam) is still common since the ban on wild seed collection in Viet Nam (Trong, Nguyen and Griffiths, 2002; Van Zalinge *et al.*, 2002). Regional transfer within Southeast Asian countries of groupers (e.g. *Epinephelus* spp.) is common; for example, China transferred wild seeds of the Hong Kong grouper (*Epinephelus akaara*) to China Hong Kong Special Administrative Region (SAR) for CBA in the 1980s after overexploitation of adult and seed resources locally (Tseng and Ho, 1988; Wilson, 1997; Sadovy, 2000). For the Japanese amberjack (*Seriola dumerili*), China and Viet Nam have exported wild seeds to Japan since the 1980s (Dao, 1999; Ottolenghi *et al.*, 2004). For the red seabream (*Pagrus major*), China Hong Kong SAR was once the major supplier of its wild seeds to Japan in the 1980s–1990s before the seed fishery dwindled (Wilson, 1997).

CAPTURE METHODS, VOLUMES AND IMPACTS ASSOCIATED WITH WILD SEED COLLECTION FOR CBA

The capture methods and associated bycatch and discards with wild seed collection for CBA, and their impacts on the environment and wild stocks are summarized for selected representative species from four major taxonomic groups, molluscs, crustaceans, echinoderms and finfishes; mortality from capture and during culture is indicated (when information is available) (Tables 3 and 4). Estimated catch volumes of wild seeds for CBA are given, when data are available (Table 5). The actual and potential problems of bycatch and sustainability in relation to catch volumes and associated mortalities are highlighted using illustrative examples. Such information is essential for identifying management issues and needs for planning future developmental directions for aquaculture. Examples are provided from each of the four groups of species.

- CBA in molluscs typically involves the collection of spats. Spats settle on specially designed “collectors” or on natural substrates, often during well-known settlement seasons and in specific collection areas. Although this approach is thought to be associated with a low level of bycatch due to the methods used, there are possible but unknown potential impact(s) from over-collection of the wild spats. Moreover, when settlement areas are modified or habitat dredged to install artificial settlement collectors, potential impact(s) on wild stocks of target or other species is (are) possible. Little is known of the early mortality rates in molluscs that would allow for management of this activity for CBA and there have been declines noted in both adults and spat supplies in areas where a wild seed collection exists for CBA for a number of species (Tables 3 and 5). Although the cause(s) for the declines is (are) unknown, given that spat catch volumes can involve tens to hundreds of tonnes (e.g. the Greenshell® Mussel *Perna canaliculus*), or tens of thousands to millions of spats, it is feasible that adult stocks are ultimately affected, especially if much of the annual settlement is concentrated in specific areas, or during specific seasons. It is quite possible that highly targeted collection of large numbers of spats could significantly affect population regeneration if a high proportion of settlers are removed for CBA each year.

TABLE 3
Selected representative species of molluscs, crustaceans and echinoderms taken for CBA with a summary of capture methods and bycatch and discards associated with the process of wild seed collection, and the impacts of CBA practice on environment and wild stocks. *, mortality from capture to harvest is indicated if information available

Representative species	Capture method	Bycatch / discards*	Impact on environment / wild stock	References
Mytilidae (mussels) <i>Mytilus edulis</i> <i>Mytilus galloprovincialis</i> <i>Perna canaliculus</i> <i>Perna viridis</i>	Natural settlement substrates (e.g. macroalgae, hard substrates); Artificial spat collectors such as longlines with fibrous ropes hang down <10 m below the water surface; By hand or divers; Dredging settlement beds	Low due to well-known settlement season and area	High through dredging, which leads to habitat disturbance or loss, change of benthic species composition, reduction of mussel growth; Wild adults and spats have shown declines	Delmendo, 1989; Hickman, 1992; Mohan Joseph, 1998; Scott and Tai, 1998; Jeffs et al., 1999; Smaal and Lucas, 2000; Dolmer et al., 2001
Pteridae (pearl oysters) <i>Pinctada margaritifera</i> <i>Pinctada maxima</i>	Artificial spat collectors such as longlines with black polyethylene shade cloth, mesh bags or tree branches hang down <5 m below the water surface; By divers; Dredging settlement beds	Low due to well-known settlement season and area	Impact through dredging is unknown, but could be the same as mussels and oysters; Wild adults and spats have shown declines; Available supply of hatchery-reared spats reduces impact on wild stocks	Gervis and Sims, 1992; Southgate and Beer, 1997; Ellis and Haws, 1999; Ponia et al., 2000; Tisdell and Poirine, 2000
Pectinidae (scallops) <i>Argopecten purpuratus</i> <i>Chlamys opercularis</i> <i>Mizuhopecten yessoensis</i> <i>Pactinopecten yessoensis</i> <i>Pecten maximus</i> <i>Placopecten magellanicus</i>	Artificial spat collectors such as longlines with polyethylene mesh bags inserted substrates (e.g. cedar leaves) or empty shells hang down below the water surface; By hand or divers	Low due to well-known settlement season and area	Wild adults and spats have shown declines; Available supply of hatchery-reared spats reduces impact on wild stocks	Lovatelli, 1987; Masuda and Tsukamoto, 1998; Ivin et al., 2006; Kosaka and Ito, 2006
Ostreidae (true oysters) <i>Crassostrea gigas</i> <i>Crassostrea plicatula</i> <i>Crassostrea rivularis</i> <i>Crassostrea virginica</i> <i>Ostrea edulis</i>	Natural settlement substrates; Artificial spat collectors such as bamboo sticks, cement bars, limed-coated roofing tiles, polyethylene ropes hang down below the water surface; Empty shells or tree branches; By hand or divers; Dredging settlement beds	Low due to well-known settlement season and area	High through dredging, which lead to change of benthic species composition; Wild adults and spats have shown declines; Disease (e.g., parasite <i>Bonamia</i> and <i>Marteilia</i> spp.) caused wild stock extinction in some areas; Disease through spat collectors of empty shells (e.g. <i>Cardium edule</i>)	Korringa, 1976a; Ling, 1977; Lovatelli, 1988a, b; Delmendo, 1989; Smaal and Lucas, 2000; Virvilis and Angelidis, 2006
Cardiidae (cockles) <i>Anadara granosa</i> <i>Cerastoderma edule</i>	Trawling sea beds with a wire basket-shaped device	Low due to well-known settlement season and area	Impact through dredging sea beds is unknown, but could be the same as mussels and oysters; Wild adults have shown declines; Limited supply of wild spats may due to the declines of wild stocks and natural low recruitment; Habitat loss may have further impact on wild stocks	Lovatelli, 1988a; Tiensongrusmee and Pontjoprapiro, 1988a; Delmendo, 1989; Burton, MacMillan and Learmouth, 2001

TABLE 3
Continued

Representative species	Capture method	Bycatch / discards*	Impact on environment / wild stock	References
Penaeidae (shrimps) <i>Metapenaeus</i> spp. <i>Penaeus japonicus</i> <i>Penaeus monodon</i> <i>Penaeus vannamei</i>	Nets (with fine mesh size) such as hand nets, push nets, dragged seine nets, bag nets, tow nets, long nets, scoop nets; Sieves; Trawls	Bycatch can be 80–99.9% and includes larvae and juveniles of commercial fishes, other crustaceans, molluscs and cnidarians; Most PL of Penaeid spp. are used for CBA, but discards are high for other groups; Mortality at capture and transportation is low (<10%) in <i>Penaeus monodon</i> to high mortality (60–70%) in hatchery-reared PL	Wild adults and PL have shown declines; Available supply of hatchery-reared PL reduces impact on wild PL but may increase impact on wild female stocks for hatchery purpose; Threat to wild stocks of other species due to high bycatch and discards	Ling, 1977; Ungson, 1990; Islam et al., 1996; Bagarinao, 1999; Rosenberry, 2000, Peterssen, 2002; SAPB, 2002
Palinuridae (spiny lobsters) <i>Jasus edwardsii</i> <i>Panulirus homarus</i> <i>Panulirus ornatus</i> <i>Panulirus polyphagus</i>	Artificial substrates; Nets such as seine nets, gillnets; By snorkelling divers; Traps; Cyanide	Low with high selectivity	Wild adults and pueruli have shown declines; Average size of fished lobsters has shown a decline; Unavailable supply of hatchery-reared pueruli and increase of pueruli demand have negative impacts on wild stocks; Habitat loss may have further impact on wild stocks; Fish and shellfish (lizard fish <i>Saurida</i> spp., red big-eye <i>Priacanthus</i> spp., pomfret, snails, mussels, oysters and cockles) are fed with poor food conversion ratio (10:1) and water pollution	Arcenal, 2004; Juinio-Menez and Gotanco, 2004; Thuy and Ngoc, 2004
Portunidae (crabs) <i>Scylla olivacea</i> <i>Scylla paramamosain</i>	Nets such as seine nets, dilly nets; Baited traps/pots; By shovels and hooks	Low with high selectivity	Increase of megalopa demand have negative impacts on wild stocks; Limited supply of hatchery-reared megalopa is not able to reduce impact on wild stocks; Habitat loss may have further impact on wild stocks	Angell, 1992; Le Vay, 2001
Holothuriidae <i>Holothuria scabra</i> Stichopodidae <i>Parastichopus californicus</i>	Artificial seed collectors such as longlines with oyster shells and cedar leaves hang down below the water surface; By hand	Low with high selectivity	Wild adults have shown declines; Available supply of hatchery-reared juveniles reduces impact on wild stocks	Tiensongrusmee and Pontjoprawiro, 1988b; Tanaka, 1992; Conand and Tuwo, 1996; Sutherland, 1996; Lovatelli et al., 2004; Tuwo, 2004; Wang and Cheng, 2004

TABLE 4

Selected representative finfishes taken for CBA with a summary of capture methods and bycatch and discards associated with the process of wild seed collection, and the impacts of CBA practice on environment and wild stocks. *, mortality from capture to harvest is indicated if information available

Representative species	Capture method	Bycatch / discards*	Impact on environment / wild stock	References
<p>Anguillidae (freshwater eels) <i>Anguilla anguilla</i> <i>Anguilla australis</i> <i>Anguilla japonica</i> <i>Anguilla rostrata</i></p>	<p>Nets such as stow nets, fixed nets, lift nets, plankton nets, dip nets, flow traps, scoop nets, hand nets, sieves; Small trawlers</p>	<p>Unknown</p>	<p>Both wild adults and juveniles have shown marked declines; Unavailable supply of hatchery-reared glass and eiver eels and high demand for them have negative impacts on wild stocks; Climate changes, oceanic current changes, water pollution, diseases, parasites and habitat loss and juveniles consumption directly have further impacts on wild stocks</p>	<p>FAO, 2002; Ringuet, Muto and Raymarkers, 2002; Knights, 2003; Ottolenghi et al., 2004; The Fisheries Secretariat, 2005; Chen et al., 2006</p>
<p>Chanidae (milkfishes) <i>Chanos chanos</i></p>	<p>Nets such as push nets, dragged seine nets, fixed nets, hand nets, scoop nets, bag nets, fry sweeper; Longlines attached with bundles of palm leaves; Traps</p>	<p>High bycatch with many other commercial fish and shrimp larvae and juveniles; High discards; Mortality at capture was <10% from most capture methods but up to 20% by fry sweepers; Mortality during storage and transportation was <10%; Mortality during grow-out period was about 50–60%</p>	<p>Wild stocks of adults and larvae have shown marked declines; Available supply of hatchery-reared larvae is far below compared to larvae demand and is not able to reduce impact on wild stocks; High demand of larvae due to the shifts of extensive (traditional) to intensive culture system, and use of prawn ponds as well as international market growth; Habitat degeneration and loss, over-fishing, water pollution and lack of effective regulation on stocks have negative impacts on wild stocks; Smuggling of wild larvae has been a major problem</p>	<p>Korringa, 1976b; Ling, 1977; Kumagai, Bagarinao and Unggui, 1980; Ungson, 1990; Pullin, 1993; Bagarinao, 1998, 1999; Ahmed et al., 2001; Liao, Su and Chang, 2001; Hong and Zhang, 2003; Rimmer, 2006</p>
<p>Clariidae (airbreathing catfishes) <i>Clarias gariepinus</i> <i>Clarias macrocephalus</i></p>	<p>Nets such as hand nets, scoop nets</p>	<p>Low with high selectivity</p>	<p>Impact of wild larvae and juvenile collection on wild stocks is unknown; Available supply of hatchery-reared larvae and juveniles reduces impact on wild stocks; Habitat loss may have negative impact on wild stocks</p>	<p>Ling, 1977</p>
<p>Pangasiidae (shark catfishes) <i>Pangasius bocourti</i> <i>Pangasius hypophthalmus</i></p>	<p>Fine-mesh "dai" nets (stationary trawls or fixed bag nets), especially for <i>Pangasius hypophthalmus</i>; Hooks (<i>Santouch Kontrey pra</i>) with baits (red ant eggs, worms), especially for <i>Pangasius bocourti</i></p>	<p>High bycatch using "dai" with most cyprinids (e.g. 75–90%); 10–30% bycatch using hooks with most other catfishes (<i>Pangasius</i>, <i>Mystus</i> and <i>Arius</i> spp.); High discards or consume by humans; 40–50% of mortality while larvae are transported to farms</p>	<p>Wild adults and larvae have shown marked declines; Limited supply of hatchery-reared larvae is not able to reduce impact on wild stocks; High demand of larvae and habitat loss have negative impact on wild stocks; Smuggling of wild larvae in Cambodia</p>	<p>Trong, Nguyen and Griffiths, 2002; Van Zalinge et al., 2002; Lieng and Hortle, 2005</p>
<p>Gadidae (cods) <i>Gadus morhua</i></p>	<p>Seine nets; Traps; Shrimp trawlers; Longlines</p>	<p>Unknown</p>	<p>Wild adults have shown marked declines; Wild juvenile collection quota for CBA reduce impact on wild stocks; Available supply of hatchery-reared juveniles reduces impact on wild stocks but culture techniques need improvement</p>	<p>Björnsson, Hugason and Gunnarsson, 2005</p>
<p>Mugilidae (mulletts) <i>Liza ramada</i> <i>Mugil cephalus</i></p>	<p>Nets such as shallow-bagged drag nets, beach seine nets, scoop nets, hand nets</p>	<p>High bycatch with about 90% catches were mullets, temperate basses and porgies, and most used for CBA</p>	<p>Wild adults, juveniles and larvae have shown declines; Limited supply of hatchery-reared juveniles and larvae is not able to reduce impact on wild stocks; Low numbers of wild juveniles and larvae may have genetic threaten on wild stocks</p>	<p>Korringa, 1976b; Major, 1978; MEDRAPTR, 1985; Chandrasekaran and Natarajan, 1993; Sadek, 2000; Sadek and Mires, 2000; Liao, Su and Chang, 2001; MEGAPECCA, 2001; Hong and Zhang, 2003</p>

TABLE 4
Continued

Representative species	Capture method	Bycatch / discards*	Impact on environment / wild stock	References
Moronidae (temperate basses) <i>Dicentrarchus labrax</i> <i>Lateolabrax japonicus</i>	Nets such as shallow-bagged drag nets, beach seine nets, scoop nets; Traps; Trawlers	Unknown	Wild adults have shown declines; Available supply of hatchery-reared juveniles reduces impact on wild stocks	Pickett and Pawson, 1994; Zheng, 1994; Sadek, 2000; Sadek and Mires, 2000
Serranidae (sea basses) <i>Cromileptes altivelis</i> <i>Epinephelus akaara</i> <i>Epinephelus awoara</i> <i>Epinephelus bleekeri</i> <i>Epinephelus coioides</i> <i>Epinephelus malabaricus</i> <i>Plectropomus leopardus</i>	Nets such as bag (=fyke) nets, fixed nets, scoop nets, push nets; Artificial reefs/shelters (=gangs); Hook-and-line; Traps; Cyanide; A wide range of methods particularly designed for early settlement stage (small juveniles) such as branches and twigs bundles and floating attractant units	High bycatch from most capture methods with high discards or consume by humans; Method of sorting leaves bycatch stranded prior to release associated with very high mortalities for some gears, such as nets and gangs; Often very high mortalities of target grouper from capture to entering culture operations for grow-out to harvest	Wild adults, juveniles and larvae have shown declines in multiple places in Southeast Asia; Some capture methods (e.g. traps and cyanide) damage habitats (e.g. corals) directly; Limited supply of hatchery-reared juveniles is not able to reduce impact on wild stocks; Habitat loss has negative impact on wild stocks	Tseng, 1983; Wilson, 1997; Tseng and Ho, 1988; Sadowy, 2000; Liao, Su and Chang, 2001; Tuan, Nho and Hambrey, 2001; Sadowy and Vincent, 2002; Estudillo and Duray, 2003; Hong and Zhang, 2003; Ottolenghi et al., 2004; Mous et al., 2006
Carangidae (jacks and pompanos) <i>Seriola dumerili (purpurascens)</i> <i>Seriola lalandi</i> <i>Seriola quinqueradiata</i>	Purse seine nets; Pair trawlers; Traps; Artificial floating substrates made from leaves and branches	Low with floating plant substrates where fish aggregation	Wild juveniles and larvae have shown declines; Limit supply of hatchery-reared juveniles and larvae is not able to reduce impact on wild stocks	Korringa, 1976b; Wilson, 1997; Ottolenghi et al., 2004
Lutjanidae (snappers) <i>Lutjanus argentimaculatus</i> <i>Lutjanus johni</i> <i>Lutjanus lineolatus</i> <i>Lutjanus russellii</i>	Nets such as push nets, gillnets; Trawlers; Traps	High bycatch with many commercial pelagic and demersal fishes	Wild adults and juveniles have shown declines; Available supply hatchery-reared juveniles reduces impact on wild stocks	Wilson, 1997; Huang, 1998
Sparidae (porgies) <i>Acanthopagrus (Sparus) latus</i> <i>Acanthopagrus schlegelii</i> <i>(Sparus macrocephalus)</i> <i>Pagrus (Pagrosomus) major</i> <i>Sparus aurata</i>	Nets such as shallow-bagged drag nets, beach seine nets, scoop nets, seine nets; Trawlers; Traps	High bycatch with many commercial pelagic and demersal fishes	Wild juveniles and larvae have shown declines; Available supply of hatchery-reared juveniles reduces impact on wild stocks	Korringa, 1976b; MEDRAP/TR, 1985; Wilson, 1997; Sadek, 2000; Sadek and Mires, 2000
Labridae (wrasses) <i>Cheilinus undulatus</i>	Hook-and-line; Gillnets; Traps; Cyanide	Unknown bycatch although cyanide likely to kill off non-target fish affected; 0–80% mortality from capture to harvest	Wild adults and juveniles have shown declines; Unavailable supply of hatchery-reared juveniles and high demand of wild adults and juveniles have negative impacts on wild stocks	Sadowy et al., 2003; Sadowy et al., 2007
Siganidae (rabbitfishes) <i>Siganus canaliculatus</i> Other <i>Siganus</i> spp.	Artificial substrates with floating grass	Low	Impact of wild juveniles collection on wild stocks is unknown	Uwate et al., 1984
Scombridae (mackerels and tunas) <i>Thunnus maccoyii</i> <i>Thunnus thynnus</i>	Purse seine nets; Tuna traps; Mid-water trawls	Low	Impacts on environment are high through high feeding levels (5–8%) and poor food conversion ratio (10–20:1); Frozen commercial fishes and squids as feeds; Wild adults have shown declines; Unavailable supply of hatchery-reared juveniles and increase of juvenile demand have negative impacts on wild stocks; Hydrological changes have negative impacts on wild stocks	Ottolenghi et al., 2004; Vita and Marin, 2007
Channidae (snakeheads) <i>Channa (Ophiocephalus) argus</i> <i>Channa micropeltes</i> <i>Channa striata</i>	Nets such as dip nets, scoop nets; Traps	Low	Impact of wild juvenile and larvae collection on wild stocks is unknown; Available supply of hatchery-reared juveniles and larvae reduces impact on wild stocks	Ling, 1977; Wee, 1981; Boonyaratpalin, McCoy and Chittapalapong, 1985

TABLE 5
Estimated, observed or inferred catch volumes of wild seeds from selected representative species taken for CBA

Representative species	Catch volume	References
<i>Mytilidae</i> (mussels) <i>Perna canaliculus</i>	In the Ninety Mile Beach (New Zealand), about 40–170 tonnes of spats were collected annually, with an increase trend	Jeffs et al., 1999
<i>Pteridae</i> (pearl oysters) <i>Pinctada margaritifera</i>	In the Manihiki Atoll (Cook Islands), 3.5 and 1 million of spats were collected in 1996 and 1999, respectively, with a decrease trend	Ponia et al., 2000
<i>Penaeidae</i> (shrimps) <i>Penaeus monodon</i>	In the Godavari estuary (India), about 1 000–5 000 post-larvae (PL) were collected per person per day in the peak season with a decrease trend in catch (e.g. 4 000–5 000 PL in 1995 and 1 000–2 000 PL in 1999) and at least 500 000 PL per day; In Bangladesh, an estimated 30 billion PL were collected per year for CBA, which was the 90% of PL population	Peterssen, 2002; SAPB, 2002
<i>Palinuridae</i> (spiny lobsters) <i>Panulirus ornatus</i>	In Viet Nam, >200 pueruli were collected per boat per night during the settlement seasons; about 2 million pueruli were collected by snorkeling divers in 2003; catch volumes of pueruli (about 7–8 mm and 0.25–0.35 g) increased from 25 000 to 126 000 from 2000 to 2002, by seine nets only in Phu Yen Province; about 50–200 pueruli (7.5–10 mm and 0.3–1 g) were collected by traps during the peak seasons of January and February per fisherman; about 100–150 pueruli (12–15 mm and 7–9 g) were collected per boat (5 divers) for 10 days	Hair, Bell and Doherty, 2002; Thuy and Ngoc, 2004
<i>Portunidae</i> (swimming crabs) <i>Scylla olivacea</i>	In Taiwan, about 60 000–70 000 megalopa were collected per fisherman per night during peak seasons	Angell, 1992
<i>Anguillidae</i> (freshwater eels) <i>Anguilla anguilla</i> <i>Anguilla japonica</i>	In Lake Hamana (Japan), the average catch was 500–600 g glass eels (about 5 000 individuals/kg) per boat per night with annual catch of 1–7 tonnes before the 1970s for <i>Anguilla japonica</i> ; In Japan, the peak year was in 1979 with 130 tonnes of <i>Anguilla japonica</i> seeds were collected, follow by a decline (58 tonnes in 1990, 20 tonnes in 1997 and 38 tonnes in 1998); In Asia (China, Japan, Korea Rep., Taiwan PC), the annual total catches were 60–155 tonnes since 2001 for <i>Anguilla japonica</i> ; In China only, about 40–95 tonnes of <i>Anguilla anguilla</i> glass and elver eels were annually imported from Europe to match the seed demand; Estimated about 100–200 tonnes/year of <i>Anguilla anguilla</i> glass eels were imported to Asia from Europe since 1996; In Europe, about 500–800 tonnes of <i>A. anguilla</i> glass eels caught in the 1980s; In France, catches of <i>Anguilla anguilla</i> glass eels (about 2 500 individuals/kg) declined from 1 345 tonnes in 1970 to 520 tonnes in 1989 and 579 tonnes in 1995; In Denmark, catches of glass eels of <i>Anguilla anguilla</i> were about 500 tonnes/year; In Portugal, catches of glass eels of <i>Anguilla anguilla</i> declined from 20 tonnes in 1976–1984 to 5 tonnes in 1997; In Spain, catches of glass eels of <i>Anguilla anguilla</i> declined from 60 tonnes in 1977 to 7 tonnes in 1997; Declines reported in European Union (EU) countries	Korringa, 1976b; Tzeng, 1997; Ottolenghi et al., 2004; COM, 2005; The Fisheries Secretariat, 2005; J.B. Liu personal communication, 2007
<i>Chamidae</i> (milkfishes) <i>Chanos chanos</i>	About 5 billion seeds were collected from Indonesia, Philippines and Taiwan PC before the 1970s, far fewer in recent years; In Philippines, about 1.35 billion, 1.16 billion and 165 million seeds were collected in 1974, 1976 and 1995 (with estimated seed demand of 1.5 billions), respectively, with a decrease trend; the CPUE was from several thousands to 20 000 larvae per fisherman per day in the peak seasons before 1980, with a declining trend (only 800–1 650 larvae in 1996–1997); In Ilocos Norte (Philippines), about 18.7 and 9.3 million larvae were collected in 1986 and 1987, respectively	Ling, 1977; Kumagai, Bagarinao and Unggui, 1980; Ungson, 1990; Bagarinao, 1998; Ahmed et al., 2001
<i>Pangasiidae</i> (shark catfishes) <i>Pangasius bocourti</i> <i>Pangasius hypophthalmus</i>	In Cambodia, CPUE for <i>Pangasius hypophthalmus</i> larvae declined, e.g. 108–165 billions (650 bag nets) in 1981, 5–12 billion (1 050 bag nets) in 1991, 2–4 billion (1 050 bag nets) in 1997, 0.9–2.1 billion (948 bag nets) in 1998–1999; In Cambodia, CPUE for <i>Pangasius bocourti</i> by hooks increased from 2001 to 2004; from 6 millions larvae/juveniles in 2001 (2 850 boats) to 3 millions in 2004 (380–470 boats); In Viet Nam, about 200–800 million larvae were collected annually	Trong, Nguyen and Griffiths, 2002; Van Zalinge et al., 2002; Lieng and Hortle, 2005

TABLE 5
Continued

Representative species	Catch volume	References
Gadidae (cods and haddock) <i>Gadus morhua</i>	In Iceland, about 500 000 juveniles with 3–10 g were collected annually since 2003	Björnsson, Hugason and Gunnarsson, 2005
Mugilidae (mulletts) <i>Liza</i> and <i>Mugil</i> spp.	In Bardawil and Manzala lagoons (Egypt), 18 million seeds (in Aug 1983–Apr 1984) with 20 mm length were caught; In Egypt, >100 million seeds were collected annually; In Greece, about 200 000 seeds were collected annually	MEDRAP/TR, 1985; Sadek, 2000; Sadek and Mires, 2000; MEGAPECA, 2001
Moronidae (temperate basses) <i>Dicentrarchus labrax</i>	In Egypt, 1 million seeds (larvae and juveniles) were collected in 1996–1997; In Turkey, a total of 3–4 million seeds (larvae and juveniles) was collected in 1995–1999;	Sadek, 2000; Sadek and Mires, 2000
Serranidae (sea baises) <i>Epinephelus</i> and <i>Plectropomus</i> spp.	In Indonesia, tens of thousands of seeds (larvae and juveniles with 10–30 mm) were collected per fisherman per night using a single unit of gear (e.g. a fyke net) during peak seasons; Overall, the regional trade must have involved tens of millions of seeds at a wide range of sizes, from post-settlement to young adults; In China Hong Kong SAR, annual Landings of <i>Epinephelus akaara</i> juveniles for grow-out was around 130–180 tonnes (about 650 000–1 800 000 juveniles of 100–200 g each) in the 1970s, mainly imported from China; In Khanh Hoa (Viet Nam), about 200 000 larvae and juveniles (including six <i>Epinephelus</i> spp. with 10–30 mm length) were collected annually in the last decade from 650 fishermen	Tseng and Ho, 1988; Sadovy, 2000; Tuan, Nho and Hambrey, 2001
Carangidae (jacks and pompanos) <i>Seriola</i> spp.	In China, about 10 million seeds were exported to Japan before the 1990s; In Viet Nam, about 450 000 seeds of <i>Seriola dumerili</i> were collected and exported to Japan for CBA in 1995; In Japan, annual catches of <i>Seriola quinqueradiata</i> juveniles (25–50 mm) were 25–55 millions since 1966, mainly remained at 25–30 millions since 1990 due to the declines of wild seeds; In Goto Islands waters (Japan), 2.5 million larger juveniles of <i>Seriola lalandi</i> (>5 kg) were caught in 1997; In Sicily (Italy), about 2 million juveniles of <i>Seriola dumerili</i> (<200 g) were collected in recreational fishing although not for the CBA	Dao, 1999; Ottolenghi et al., 2004
Sparidae (porgies) <i>Sparus aurata</i> <i>Pagrus major</i>	In Bardawil and Manzala lagoons (Egypt), 800 000 (in Apr–May 1983) and 8 million (in 1984–1985) juveniles with 20 mm/2 g were collected, respectively; In Egypt, 3–4 million larvae (0.25–0.5 g) and juveniles (1–10 g) were collected (10 million estimated by fishermen) with one million from hatchery in 1996–1999; In Turkey, a total of 140–160 million seeds (larvae and juveniles) was collected in 1995–1999; In Hong Kong SAR, about 6 million juveniles were collected and exported to Japan for CBA in the 1980s–1990s, and hard to catch now	MEDRAP/TR, 1985; Wilson, 1997; Sadek, 2000; Sadek and Mires, 2000

- Crustacean wild seeds are collected by various methods for CBA and, as for molluscs, seed collection tends to be concentrated in specific locations and seasons when large numbers become temporarily available (Tables 3 and 5). For shrimps, the process of wild seed collection involves nets of various types, from push nets to towed/dragged nets in shallow coastal waters or creeks. Bycatch using such gears can be high from Asian and South American countries (e.g. Bangladesh, India, Malaysia, Philippines and Ecuador) and involve a variety of larvae and juveniles of commercial fishes and crustaceans as well as discards depending on the area fished (Pettersson, 2002; SAPB, 2002; M.L. Cobo personal communication, 2007). Many millions of shrimp post-larvae are collected in the season within small areas (Table 5); mortality levels from capture to transfer to ponds appear to be low for at least one species (*Penaeus monodon*) (Pettersson, 2002). For lobsters, wild seed are collected using artificial substrates on which the pueruli settle, as well as by nets of various kinds and while diving (with collection by hand or using cyanide) in some cases. Declines in seed availability have been noted in Asian countries.
- The relationship between the collection of very early stage seeds and the status of adult stocks has been shown in a few species identifying the need for a holistic look at such fisheries. For example, a relationship between settlement stage pueruli and numbers of resulting lobster adults was identified in Australia (Phillips *et al.*, 2003; Gardner *et al.*, 2006). This finding is extremely important for highlighting the link between settlement numbers and subsequent adult stock size and for setting a fishery quota for both pueruli and adults in this case. For mud crabs, nets, pots, shovels and hooks are all used to collect megalopa with catch rates estimated in one place at 60 000–70 000 per fisherman per night in the peak seasons, which may have negative impacts on wild stocks (Angell, 1992).
- Small holothurians are taken for CBA using specially designed seed collectors and by hand. Adult stocks of a number of species have shown marked declines and populations of some species have suffered over-exploitation for decades in some Asian countries (Lovatelli *et al.*, 2004). Hatchery-based holothurian aquaculture (e.g. Japanese sea cucumber *Apostichopus japonicus*) has been well-developed in China in recent years (Chen, 2004); whether HBA of holothurians can reduce the impact on wild stocks and help stock recovery needs further investigation.
- In finfishes, seeds of a wide range of sizes are taken, and in large numbers, from settlement stage larvae through to adults. Adult and seed stocks have shown marked declines in almost all representative species, the result of some combination of over-exploitation of wild stocks of adults and seeds, habitat loss, etc. The heavy take of seed for some species is also prompted by the limited supply of hatchery-reared seeds (Table 4). Associated with seed collection, bycatch and mortalities can be high, leading to much wastage of target and non-target species in some areas or during certain activities. Examples include milkfish in Indonesia and the Philippines, shark catfishes in Cambodia and Viet Nam, mullets in Egypt, sea basses, snappers and porgies in Southeast Asia and Egypt (Table 4). In these species, capture methods range from nets, traps, hook-and-lines and trawlers, to chemicals and artificial shelters; many methods are not species-specific and can cause significant habitat disturbance and damage. Although bycatch species containing some commercially important finfishes and shrimps can also be used for CBA, most tend to be discarded, while a few might be consumed by humans, depending on size.

CBA PRACTICES IN RELATION TO DISEASE, ENVIRONMENT AND BIODIVERSITY

CBA practices need to be considered in relation to disease transfer and environmental impacts including on species diversity. Although these issues are also relevant to HBA, there are certain considerations specifically or indirectly pertinent to CBA practices

because some of the impacts on biodiversity are negative (Beveridge, Ross and Kelly, 1994). There are no clear positive impacts on biodiversity yet noted in relation to CBA. Clearly, both CBA and HBA practices are associated with a number of problems such as water pollution and environmental damage, which are exacerbated where CBA is extensively practised simply because CBA means higher volumes of animal under culture (Tables 3 and 4). With the extensive development of CBA practices and increasing transport and trade of wild seed both regionally and globally, problems of disease and genetic pollution associated with transfers and escapes of wild seeds may be a matter for concern. Below are some examples that illustrate the problem.

- In the case of *Epinephelus* groupers, a *Vibrio* strain in *Epinephelus bleekeri* was transferred from Thailand to China Hong Kong SAR in wild caught seeds and resulted in the elimination of almost all cultured groupers in China Hong Kong SAR in the late 1990s, a serious blow to the industry at the time which took several years to recover (Sadovy, 2000).
- Environmental impacts from CBA practices need to be addressed. Low environmental impacts from CBA practice for *Anguilla* eels are assumed because artificial feed rather than natural feed is provided and because land requirements are low for intensive culture practices in both Asia and Europe (Ottolenghi *et al.*, 2004). However, unregulated use of groundwater for eel culture in China and Taiwan Province of China (Taiwan PC) has caused severe land subsidence (Chen *et al.*, 2006). Moreover, the high demand of fish-meal for eel feed and the use of chemicals for disease treatment and prevention during eel culture in China need to be addressed.
- All crustaceans and a significant number of finfishes in CBA are carnivorous and require feed input that includes wild-caught fish (i.e. fresh feed input). While these are also relevant to HBA species, the extensive use for CBA, especially for carnivorous species, can add significantly to the problems that such practices cause. Uneaten feed, faecal and urinary wastes may have negative environmental impacts and lead to local water quality degradation and sediment accumulation (Wu, 1995). For example, in a tuna (*Thunnus thynnus*) fattening culture farm in the Mediterranean Sea producing 800 tonnes of tuna a year, the use of defrosted fish was shown to affect the benthic environment over an area 400 m diameter, an impact considerably greater than other fish culture practices in the same area (Vita and Marin, 2007). Study of carrying capacity of the local environment (i.e. the maximum numbers of animals or biomass that can be supported by a given ecosystem for a given time) is particularly important for aquaculture practices of this sort which, although they can produce a valued product, can also cause more wide-ranging negative impacts on the natural environment.
- Possible adverse biodiversity impacts from CBA practices in relation to global *Anguilla* eel seed trade are of interest. The introduced European eels (for CBA and restocking purposes in Japan) have been found free in Japanese natural waters in recent years with the silver stage eels migrating downstream at the same time as native Japanese eels form downstream migrations (Miyai *et al.*, 2004). The potential impacts of inbreeding between the two species and on local aquatic biodiversity should be examined, since eels are important predators in freshwater benthic habitats.
- The HBA culture of a number of tropical marine fish species will continue to depend to some degree on wild broodstock to maintain genetic diversity, for feed, and, in some cases, continued contribution of wild seed. In many cases, not only is the target species removed but also a heavy bycatch component. For instance, for 1 kilogram of shrimp post-larvae collected, an estimated 10 kg of larvae and juveniles of other species may be discarded (Beveridge, Ross and Kelly, 1994). More extreme ratios are likely in certain fisheries for grouper juveniles (Mous *et*

al., 2006). Heavy exploitation for target species can mean extremely high levels of associated bycatch with the potential for negative impacts on biodiversity. More generally, high densities of farmed fish and food attract predators that could, conceivably have an impact on local species, while the heavy demand for wild fish feed and fishmeal, intensified by CBA, is exerting growing pressures on such species; in extreme cases this could affect local biological diversity (Beveridge, Ross and Kelly, 1994; Naylor *et al.*, 2000).

MANAGEMENT

Current and recent management measures as well as those being developed that are applicable to various aspects of wild seed fisheries associated with CBA are summarized and discussed. Regulations on marine and freshwater invertebrates and vertebrates from around the world are selected to provide a cross-section of the types and extents of protective measures (Table 6). The selection is illustrative, rather than exhaustive.

The development of management measures has been a response to problems noted in various fisheries, usually declining catches but sometimes concern over bycatch or damage to substrate. In some cases the cause of the problem is clear or can be reasonably attributed to a specific cause or causes, but in others, the reason for problems is not necessarily clear and management is precautionary or based on the best available scientific information. Management measures to address overfishing that have been introduced or are under discussion range from gear controls to catch quotas (e.g. total allowable catch), limited fishing seasons and export controls, size controls, permit issuance, rights of access to fishing grounds, to genetic pollution and disease controls.

In cases where habitat damage is a major concern because seed capture methods involve removal of habitat, fishing gears that move closely over the substrate, or poisons, measures used include bans, modification of fishing gear and protection of larval and juvenile settlement or nursery areas. Where there are concerns about possible impacts on biodiversity of non-target stocks, largely because of bycatch, measures address gear characteristics and may involve training fishers in better handling techniques for reducing mortalities. Example include, more careful transfers during transport, lower densities of storage and transit, more oxygenation as needed, etc. Other measures tackle concerns about disease transfer, as seed have increasingly been traded (exported or imported) or exchanged as part of a valuable seed market, with possible genetic “pollution” from reintroductions or escapes of genotypes into non-native areas.

Typically and not surprisingly, wild seed fisheries for CBA often begin with no management and are practised for decades, sometime generations, with little or no controls. Examples range from molluscs, catfish, mullets and milkfish to groupers and eels. Seed fisheries were largely excluded from formal legislation in the past. This is possibly because of their low perceived value and impact and limited information availability. It may also be because of a general perception that taking seed was somehow getting “something for nothing”; that removal of larvae and small juveniles did not affect adult populations because most would die naturally if not fished – indeed CBA is more likely to be viewed to be a means to gain a net increase production. When fishing pressure was low, this may well have been the case. As fishing pressure and demand for seafood increased there has been a general intensification of fishing, including on seed fisheries. In the case of mussel from New Zealand, it is quite possible that highly targeted collection of large numbers of spats could significantly affect population regeneration since a high proportion of settlers are removed for CBA each year. It is only in the last decade or so, often only after stocks have been very severely reduced, or where there are conflicts identified between users of different life history stages of a species (e.g. in the cases of lobsters, shrimps, shark catfishes, eels and tunas) that management is discussed and legislation developed, and the biological and ecological links formally acknowledged. The high value luxury seafood seed fishery sector,

TABLE 6
Examples of current/recent and/or potential management measures for wild seed fisheries and trade for CBA

Country	Current and/or potential management measures	References
EU countries	<p>Species management</p> <p>European eel (<i>Anguilla anguilla</i>): wild seed collection of eel elvers needs permit in France; massive declines of eel stocks have prompted the discussion for management which is complicated by the very variable fisheries across Europe (shared resource); a recent proposal from the Commission of European Communities includes a seasonal closure of its fishery (the first 15-day closure each month) since July 2007, restoration of habitat and migration paths, and better fishery regulation, anti-poaching action and improvement of water quality are proposed; by 2013, 60% of catches of glass eels should be used for restocking of inland waters so as to increase escapement of adult eels to the sea;</p> <p>Mulletts: wild seed collection of mullets needs permit in France; maximum collection was controlled at 200 000 seeds in Greece;</p> <p>Tuna (<i>Thunnus thynnus</i>): catch quota for CBA in the Mediterranean Sea;</p> <p>Cod (<i>Gadus morhua</i>): <500 000 juveniles (maximum quota) with 3–10 g allowed to collect annually since 2003 for CBA in Iceland;</p> <p>Mussels: mussel spat collection in Italy are managed including rearing or stocking purposes during certain periods per year, spat collection quotas, maximum size, gear limit, hygiene requirements for the transportation of spats intended for rearing and repopulation purposes;</p> <p>Clams: clam spat collection in Italy are managed including rearing or stocking purposes during certain periods per year, spat collection quotas, maximum size, gear limit, hygiene requirements for the transportation of spats intended for rearing and repopulation purposes;</p> <p>Multiple species: no wild seed collection (all species except mollusc seeds) allowed since 1992 in Portugal.</p> <p>Input control</p> <p>Local management in size limits, permits, close seasons and areas, restoration of habitat and migration paths.</p>	<p>MEDRAP/TR, 1985; Gazzetta Ufficiale della Repubblica Italiana, 1996; Sadek and Mires, 2000; Ringuet, Muto and Raymarkers, 2002; Ottolenghi et al., 2004; Björnsson, Hugason and Gunnarsson, 2005; COM, 2005; The Fisheries Secretariat, 2005</p>
China	<p>Species management</p> <p>Groupers (<i>Epinephelus</i> spp.): control on number of "seed" collection fishers and amount of "seed" captured;</p> <p>All marine species: license is needed for transporting marine "seed" and export of "seed" is banned to prevent infections or parasites.</p> <p>Input control</p> <p>Illegal fishing (e.g. poison, blasting) is prohibited.</p>	<p>National People's Congress Order, 1991; Sadovy, 2000</p>
Taiwan PC	<p>Species management</p> <p>Groupers: in the Penghu Islands, harvest of grouper seed <60 mm is not permitted.</p> <p>Input control</p> <p>Cyanide cannot be used for fishing (this regulation occurs in many countries and in relation to fisheries in general, not just seed).</p>	<p>Petersson, 2002</p>
India	<p>Species management</p> <p>All aquatic species: the ban on wild seed collection year-round was announced in 1999 through the State of Fisheries Department and is still valid; local government lacks the economic support to implement this ban; wild seed collection continues.</p>	<p>Sadovy, 2000; Sadovy et al., 2003</p>
Indonesia	<p>Species management</p> <p>Humphead wrasse (<i>Cheilinus undulatus</i>): wild collected <1 kg and >3 kg fish should be used for CBA or released; capture methods limit to hook-and-line, traps and gillnets; permit is needed for purchase and export 1–3 kg fish.</p>	<p>Sadovy, 2000; Sadovy et al., 2003</p>

TABLE 6
Continued

Country	Current and/or potential management measures	References
Philippines	<p>Species management</p> <p>Lobsters: export of juveniles was banned prior February 1992 but subsequently lifted;</p> <p>Humphead wrasse (<i>Cheilinus undulatus</i>): small wild collected fish (<300 g) should be used for CBA;</p> <p>All CITES species: ban from export;</p> <p>Milkfish: the Fisheries Code of 1998 bans export of "seed" of milkfish; fishing of broodstock (<i>bangus</i>) is banned;</p> <p>Prawns: the Fisheries Code of 1998 bans export of "seed" of prawns;</p> <p>All live fishes: strictly speaking, the export of any live fish (include seeds) is illegal but this is not enforced.</p> <p>Input control</p> <p>Scissor (push) and fyke (bats) nets fishing are illegal;</p> <p>Poison fishing is illegal.</p> <p>Fishing ground management</p> <p>Regulations intended to protect some seed collection grounds (e.g. milkfish) and nursery grounds as "fry reservations" have not been implemented.</p>	<p>Sadovy, 2000; Ahmed <i>et al.</i>, 2001; Sadovy <i>et al.</i>, 2003; Juninio-Menez and Gotanco, 2004</p>
Malaysia	<p>Species management</p> <p>Groupers: no grouper seeds can be collected during the peak season; no export of grouper seeds <150 mm;</p> <p>Cockles: removal of cockle spat from a natural cockle bed or cultured cockle bed are banned.</p> <p>Input control</p> <p>Cyanide fishing is prohibited.</p>	<p>FAL, 1986; Fisheries (Riverine) Rules, 1990; Sadovy, 2000</p>
Australia	<p>Species management</p> <p>Tuna (<i>Thunnus maccoyii</i>): fishing season and TAC (expressed as weight) of juveniles for CBA are regulated;</p> <p>Rock lobster (<i>Iasus edwardsii</i>): to ensure "biological neutrality" between CBA and adult capture fisheries for the species the number of pueruli that can be removed cannot exceed 300 000 annually (calculated using virtual population analysis); pueruli below 76 mm carapace length are protected; applications for culture consider issues of genetic contamination and disease; restocking of partially raised young to enhance capture fishery.</p>	<p>Ottolenghi <i>et al.</i>, 2004; Gardner <i>et al.</i>, 2006</p>
Thailand	<p>Input control</p> <p>The use of push nets and fyke nets is limited;</p> <p>The use of bottom nets fishing within 3 km of the shore are regulated;</p> <p>Mesh size ≥ 25 mm.</p>	<p>Sadovy, 2000</p>
Viet Nam	<p>Species management</p> <p>Groupers: <500 g cannot be exported.</p> <p>Input control</p> <p>Fine-mesh <i>dai</i> nets (stationary trawls) are totally banned in some provinces since 2000, which especially for capture wild larvae of shark catfish <i>Pangasius hypophthalmus</i>.</p>	<p>Sadovy, 2000</p> <p>Trong, Nguyen and Griffiths, 2002; Lieng and Hortle, 2005</p>
Cambodia	<p>Input control</p> <p>Fine-mesh <i>dai</i> nets (same as above) were outlawed in 1994 but still used by 1998.</p>	<p>Lieng and Hortle, 2005</p>
Bangladesh	<p>Species management</p> <p>Shrimp (<i>Penaeus monodon</i>): permits needed, fishing season controlled, restocking of hatchery PL₁ reducing bycatch by training fishers for better handling of PL and create alternative livelihoods to remove pressure from wild PL collection.</p>	<p>SAPB, 2002</p>

including for southern bluefin tuna, lobster and grouper, have provided much incentive for sustainability. Management has developed quickly that explicitly addresses the links that exist between adults and pre-adult phases taken by different fisheries.

As fishing, in general, has intensified, it is not surprising that the potential for adult capture fisheries and seed fisheries to affect each other has been realized to the extent that there are now management initiatives that seek to ensure that the two fishing sectors are not in conflict by using stock analyses. This will have to be one of the approaches to management in future if stocks are to be sustained, if equity is to be considered between fishing sectors, and if conflicts over resource use are to be minimized and management aims for sustainable practices realized. This balancing of differential life history phase use is referred to under the general name of “biological neutrality” (Gardner *et al.*, 2006).

For insight into some of the complexities and issues involved in conserving seed fisheries, the long-standing European eel fishery serves as a good example. Declines in European eel catches, including glass eels, elvers and adults, have occurred throughout the range of the species; the exact cause is unknown. Likely causes are a combination of over-exploitation, oceanographic or climate change, freshwater habitat degradation and pollution, and disease, although overexploitation is clearly one important factor (Knights, 2003; Starkie, 2003; Van Ginneken and Maes, 2005). Since so little is known about the life history stages of the European eel, planning for its sustainable management is a difficult challenge and it is only very recently that serious discussions have started to address the long-recognized, albeit little acknowledged, declines in catches (Table 6). Most recently, a study demonstrated genetic differentiation in the European eel indicating that the species consists of several stocks and not just one, as previously thought (Wirth and Bernatchez, 2001). This information is important for assisting protection because it identifies the geographic scale at which management might be most effective and indicates that the massive transfers of seed that have occurred widely within Europe should be restricted or carefully controlled.

Shrimp seed fisheries can be extremely complex; many have a long history of fishing with the involvement of many different user groups. In one area of Bangladesh, for example, the interest groups for shrimp production range from shrimp farmers, biologists and government, to the fishers and hatcheries that supply the farms and exploitation on both adult and seed stocks all have very different needs and opinions on how to deal with the marked declines noted in one of the two shrimp species they commonly exploit (SAPB, 2002). The long history and complexity of this situation makes management extremely difficult and provides a lesson that management should start early in fishery development rather than long after major conflicts and resource declines have occurred and many users or user groups become involved and dependent.

In summary, the management experience for seed fisheries is extremely varied, most is very recent, and little appears to have been effectively implemented to date. There is little evidence of monitoring of seed fisheries in general, which is essential for understanding the effects of management, or of enforcement. It is clear that many of the management challenges stem from the complexities of understanding and assessing fisheries acting at different life history stages, especially when one of these, the early life history “seed” stage is little understood (either biologically or as a fishery). The general assumptions surrounding the impacts, or, rather, the lack thereof, of removing early life history phases, on later adult stages or wild populations have precluded management discussions until recently.

Regulations that address seed fisheries must focus on specific aspects of the problems encountered and not just treat them as fisheries of “undersized” individuals, except, perhaps in cases such as of the humphead wrasse and bluefin tuna. The problems are compounded when other factors, such as habitat degradation, destruction or water pollution may also be major factors in declines noted. What is clear is that

seed fisheries are important and likely to be important for a long time since HBA (i.e. full-cycle aquaculture) is only viable for a small subset of aquatic species. Even in species for which hatchery-reared seed are available, issues of seed “quality”, HBA production volumes and costs may mean continued pressure on wild stocks to provide high quality, inexpensive seed. Farmers may prefer wild-caught seeds in some areas, such as milkfish in the Philippines, shark catfish in Viet Nam, shrimps in Bangladesh, or economic factors might mean that wild-sourced seeds are sometimes cheaper than those of the same species that are hatchery produced, as in the case of several grouper species in the Taiwan Province of China culture sector (Sadovy, 2000). The issue of management of wild populations in CBA, therefore, must be addressed, and must specifically seek to tackle the characteristics of “seed” fisheries.

FUNDAMENTALS OF CBA PRACTICE

Several aspects of seed fisheries for fish and invertebrate species can be considered of theoretical importance because they are fundamental to sustainable resource use, yet are either very little understood or extremely difficult to quantify. Therefore, the precautionary approach can, combined with the best available information and scientific reference, address key issues. Central to these, in relation to CBA, is the nature and extent of the linkage between wild seed collection of early life history stages and the condition of adult stocks, and how to manage different fishing sectors exploiting the same species. The key biological information needed includes density-dependent effects among seed, and age-specific natural mortalities, both of which are virtually unknown for marine species with planktonic larval stages. These parameters are of critical importance because they dictate how many seeds can be removed from the wild without affecting adult stock numbers.

For some species there is a known quantitative relationship between seed numbers and adults, while for most a relationship is not clear, the implications being that density-dependent effects and total mortality (i.e. natural plus fishing) levels probably have very different significance for different species, or depending on the age of the seed at capture. Illustrative examples are lobster and shrimp. For tiger shrimp (*Penaeus monodon*), the post-larval fishery removes an estimated 90 percent of the seed population, which scientists believe is largely responsible for the heavy declines in the adult shrimp fishery off Bangladesh; in the case of *Metapenaeus monoceros* taken in the same general area, however, the adult fishery is in much better shape because, it is thought, there is little vulnerability of the post-larvae to fishing; less than 10 percent of this early stage is removed by fishing (SAPB, 2002). In the case of lobster, natural mortality estimates of *Panulirus cygnus* in western Australia suggest that this is regulated by density and is so high that even very large removals of pueruli are expected to have negligible effects on wild fisheries (Phillips *et al.*, 2003). For the rock lobster (*Jasus edwardsii*), on the other hand, collection of pueruli potentially affect adult numbers and so there is interest in attaining “biological neutrality” whereby excessive seed removal does not compromise the adult fishery (Booth, Davis and Zane, 1999; Phillips *et al.*, 2003; Gardner *et al.*, 2006). The degree to which density-dependence is important will depend, in part, on whether stocks are habitat or recruitment limited. As fishing pressures increase, the latter becomes more likely and the relevance of density-dependence is likely to decline substantially. Very little is known about either natural mortality levels early in life or the extent to which density-dependent effects can and do occur under different conditions suggesting that a precautionary approach is applicable.

What is known about density-dependent effects and early natural mortality rates in finfishes subjected to seed fisheries that can assist management decisions? For a few reef fishes, although early juvenile survivorship varies among species in the first few weeks or months following settlement, indications are that natural mortality, very high at settlement, drops quickly during the first few months post-settlement

(Sale and Ferrell, 1988; Koenig and Colin, 1999; Doherty *et al.*, 2004). For such species, the intense exploitation of older juveniles (which have entered a low natural mortality stage) for CBA clearly increases fishing mortality directly on the stock as a whole, and the fishery should be managed to ensure that sufficient young are allowed to survive to reproduce for population persistence (Sadovy and Pet, 1998; Sadovy, 2000). A specific example of this is the fishery for grouper juveniles, many of which are several years old at capture and are removed prior to sexual maturation for grow-out in captivity to marketable size (Sadovy, 2000). This practice has increased over the last decade as adult stocks have become over-fished, the demand for seed has increased and fishers take ownership of caught fish as soon as they can rather than return undersize fish to the water (Sadovy, 2000; Sadovy *et al.*, 2003). The impact of removing grouper juveniles at one week of age or less, compared to removing the same number of juveniles at 6 months or more (both practices are common) could mean the difference between healthy and devastated stocks. In the case of the older juveniles, their capture and the addition of feed is no different from the fattening of juveniles of bluefin tuna species.

A precautionary approach to seed fishery extraction rates, based on what is known currently, and acknowledging how much is still unknown about early life history stage dynamics, is to assume some degree of linkage between adult and seed fisheries and manage accordingly. This approach is already practised in the case of southern bluefin tuna through catch quotas on juveniles taken for fattening and for rock lobster (Gardner *et al.*, 2006) (Fishery Status Reports, 2005; 2006); such quotas should be in numbers, rather than weight. Follow-up monitoring allows for adaptive management and adjustment of fishing levels as needed. This precautionary and adaptive approach is particularly relevant as seed fisheries intensify, with possibly billions rather than millions of seeds taken each year, and given how challenging it will be to collect the necessary natural mortality and density-dependent information. Key to such thinking is to acknowledge that the production of large numbers of eggs and larvae in pelagic spawning species is not a redundancy but a fundamental life history strategy. Enormous numbers are produced for a simple but compelling reason – the very low chances that any one propagule will survive to adulthood. Removing a significant number by fishing will inevitably further reduce that possibility to some extent, with negative implications inevitable beyond some threshold of removals. Fisheries for aquarium organisms and food fish, based on the capture of post-larval settlement phase fish, have been proposed as a viable alternative activity to adult capture, although nothing is known of the volumes of post-larvae that could be removed sustainably (Hair *et al.*, 2004). A better understanding of such thresholds is needed and/or a means found to ensure it is not exceeded, thereby compromising affected fisheries and the livelihoods that depend on them.

RECOMMENDATIONS

CBA is an economic activity that will almost certainly expand in the short term, and is very likely to continue into the long term for many species. CBA is practised because it has become necessary as a livelihood, as an alternative means to controlling access of fishery resources, to meet market demand and, if practised properly, to enhance yield. It does not necessarily, or even desirably, lead to HBA and does not demonstrably take pressure off wild stocks. For example, despite decades of *Anguilla* CBA, successful HBA is far from certain. Moreover, new species will likely become the focus of CBA while a few species will eventually move to successful hatchery production. Even in the latter case, as for groupers, a mixed model might persist whereby both HBA and CBA practices occur; it took over 10 years to reach successful grouper HBA for just a few species while many others (e.g. the Hong Kong grouper *Epinephelus akaara*) continue to be exploited under CBA despite capacity for HBA. The bottom line, it

seems, is that CBA is here to stay and means must be sought to ensure its sustainable practice. Whether or not CBA, or HBA, will take pressure off wild fisheries is entirely another matter that would require specific legislation whereby CBA development is balanced by a corresponding and specific reduction of fishing pressure in concert with CBA expansion. While, for example, the supply of hatchery-reared juveniles for backyard grow-out of groupers in Indonesia is claimed to have reduced cyanide fishing by replacing fishing with culture practices, there are no quantitative data to support this and no relevant legislation to mandate a the shift from capture to culture.

CBA is truly a hybrid between capture fisheries and aquaculture, with many of the advantages and disadvantages inherent in both activities. Important as an alternative livelihood, CBA also offers opportunities for the development of HBA. However, CBA is not necessarily a stepping stone between the two but rather an activity in its own right which will certainly continue. Because of the impacts and implications of CBA, it needs to be acknowledged as distinct sector and integrated and managed accordingly as a specialized, albeit little understood type of fishery. This means that the objectives of CBA must be clear, the risks identified, activities clearly defined, and practices developed or modified to address the negative aspects of the practice and enhance the benefits.

Based on the present review, eight specific recommendations are proposed to improve CBA practices in a way that will address many of the shortcomings documented:

- **Precautionary approach and FAO Code of Conduct:** There is a need to adopt the precautionary approach in CBA. There is a little biological understanding of early life history stages of species under CBA, and they receive negligible management attention. Moreover, the principles and guidelines of the FAO Code of Conduct for Responsible Fisheries should be applied because CBA involves capture fisheries.
- **Mortality:** There is a need to be realistic. While very early settlement stage larvae almost certainly suffer high mortality reducible by judicious removal from the wild and culture, propagules are not infinite for any species and the highly focused removal of millions to billions of seed will ultimately compromise stocks. Much CBA is practised on older post-settlement stages, in effect capture fisheries of juveniles, that need to be managed accordingly. Management that takes such realities into account need to be developed for many of the CBA species reviewed, and training and outreach is needed to reduce mortalities associated with a range of capture, transfer and culture practices.
- **Bycatch:** In addition to a high capture and culture mortality, there is, for many of the representative species reviewed, a high and often diverse associated bycatch. This aspect of these fisheries can severely undermine the perceived advantages of CBA and measures should be made to develop more selective gears, or, fish in a way that minimizes wasteful bycatch.
- **Objectives of CBA:** The objective(s) of CBA must be clear if it is to capitalize on its potential and be managed and practised sustainably. Nowadays, CBA is largely an economic activity involving many high value species and not necessarily practised with the objective of producing basic, low-cost, seafood for sustenance. It is, therefore, not currently practised as an alternative to fishing for food per se. Rather, it is as an economic activity in its own right, provides livelihoods, and, perhaps, is a means of gaining access to, and control of, increasingly limited resources earlier in their life history. It is only by acknowledging its role in practice that it can be managed effectively.
- **Management:** Management and better practices are possible only when activities are recognized, acknowledged and documented. CBA needs to be monitored and a better understanding of its direct and indirect impacts on targeted and non-targeted (bycatch) species considerably better understood. Other impacts, such

as the effects of fishing gears, have been widely acknowledged and need effective management. Considerations of equity of resource access and user conflicts should be factored into management plans. Moreover, even HBA will depend for genotype refreshment from natural broodstock, such that wild populations will continue to need management. Finally, for managing late stage CBA (e.g. as for tuna), if most juveniles removed are likely to survive to adulthood, it makes more biological sense to manage by number of fish in a quota, rather than by weight as is currently done.

- **CBA to HBA:** It is clear that not all CBA leads to HBA and that mixed models are likely to persist long into the future. For many species, the focus on CBA versus HBA will depend on economic factors and whether CBA moves to HBA is both an economic and a technical matter, and far from inevitable. It may not even be desirable that all mariculture becomes HBA because of the possible control on seed supply by big business that HBA would foster, with possible negative impacts on wild seed prices and livelihoods of seed collectors. Given the inevitable and probably advisable, mixed model, the relationships between the two activities need to be acknowledged and managed practically and realistically.
- **Definitions:** The perspectives on how to manage, understand and monitor CBA are heavily shaped by how it is defined and what are the objectives in its application. The recent introduction of the term CBA has been enormously helpful in better understanding and more easily discussing it. However, the documentation of CBA-cultured species in FAO records appears to be unnecessarily complicated and somewhat misleading. We propose a simpler and more representative set of definitions that directly reflect the nature of CBA in relation to wild resources. For documenting and reporting culture production, we suggest two major categories; “hatchery” and “non-hatchery” sources of seed. Under non-hatchery sources, a subdivision could be used to distinguish between “growing-out” (of eggs, larvae, very early post-settlement stages) and “fattening” (the increase in bulk of settled/juvenile animals or their maintenance until retail). The former would include spat, post-larvae and small juveniles of fish and invertebrates and the latter would include large juveniles and young adults, for example of groupers and tunas. The intention is to distinguish between seeds taken at very high natural mortality stages and seeds taken once natural mortality has likely dropped to near adult levels. Both categories of non-hatchery produced seed would need to be managed and monitored.
- **Species cultured:** The culture of fish centuries ago began with CBA practised on herbivorous and omnivorous species, such as carps, milkfish, mullets, eels and tilapias to address basic needs for food, while expensive, luxury, and carnivorous species appeared only after the 1940s (Ling, 1977; Beveridge and Little, 2002). If CBA is to be used for food security there has to be a greater focus on species that can provide cheap food and do not involve the many problems associated with carnivores in culture and capture. Again the “Objectives” of CBA need to be clear, i.e. why do we need CBA and how can we use it to best advantage? There are tradeoffs to different objectives and some are mutually exclusive: provision of livelihoods for seed supply may compromise the fishery of adults of the same stock; the use of ponds for expensive grouper culture may mean that cheaper food fishes are displaced; in both cases poorer communities might lose out; the removal of massive volumes of fish feed may compromise the feed species (many of them the young of cheap fish consumed by humans) captured, or the ecosystems they belong to. Without clear principles and guidelines, and a realistic evaluation of the constraints and problems associated with CBA, this form of culture cannot realize its full potential and, far worse, may further compromise natural marine resources and human communities.

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Social and economic impacts of capture-based aquaculture

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SUMMARY

This paper reviews the social and economic impacts of capture-based aquaculture, and specifically the capture of early life-history phase animals from the wild for use as seed material in marine and freshwater grow-out. The considerations and impacts highlight the overlap of capture fisheries and aquaculture in capture-based aquaculture. Capture-based aquaculture has social and economic advantages and disadvantages compared to full-cycle aquaculture. In many situations, especially in developing countries, capture-based aquaculture can provide income and livelihoods to sectors of the population that may otherwise be excluded from aquaculture. However, it can also result, among others, in conflict and the loss of societal benefits from the loss in yield from the wild stocks. Markets have been the driving force behind the development of the capture-based aquaculture industry as the selection of species for culture reflects demand in local and international markets and consumer's tastes and preferences. It is expected that markets will continue to drive development in the future. It is anticipated that capture-based aquaculture will continue to expand in the short-term, both for those finfish and non-fish species currently being cultured and possibly with others that may be selected for aquaculture in the future. Other economic issues include costs and profitability (private and social), market channels and externalities. Social issues include employment, livelihoods, rural development, property rights, conflicts, technology, culture/traditions, ethical opinions and public participation. The main constraint to expansion is "seed" supply. Wild seed supply has not been able to keep up with the increasing demand from farms. The capture of wild seed is being increasingly regulated. It is important that means be found to rear these species throughout their full life-cycle that are economically viable. Farmers will also need to reduce their production costs to meet changing market demands. Any future expansion of capture-based aquaculture will also need to address potential damage to the environment caused by its activities and regulate itself in a more sustainable manner. In all cases, there will be positive and negative social and economic impacts that will need to be managed more strategically.

INTRODUCTION

Aquaculture is seen as a solution and alternative to meet current and future demand for aquatic products. However, many aquaculture practices still need considerable refinement to make them more sustainable and to reduce their dependence on wild fisheries stocks and to avoid harming aquatic habitats (Naylor *et al.*, 2000). Major

constraints in the development of sustainable aquaculture include the continuing dependence on small low value or bycatch fish, commonly called trash fish, for feed, and environmental impacts such as nutrient discharge into coastal waters. Another constraint is the capture of early life-history phase (ELP) animals (i.e. settlement stage larvae, fry, fingerlings and juveniles) or “seed material” from the wild for grow-out to market size in aquaculture facilities (Mous *et al.*, 2006). Sustainable access to fry and fingerlings can constitute a significant constraint to aquaculture development. This practice has been called “capture-based aquaculture” to address the overlap between capture fisheries and aquaculture (Ottolenghi *et al.*, 2004). This activity is reported in FAO statistics as aquaculture rather than capture fisheries even though it depends on seed supply from the wild rather than from hatcheries.

Capture-based aquaculture has developed due to the market demand for some high value species whose life cycles cannot currently be closed on a commercial scale. In addition, the hatchery production of many cultured species is still well below demand and is constrained by poor and unreliable survival of larvae in hatcheries. Supplies of fry and fingerlings of many cultured species taken from the wild have declined and these declines are likely caused by overfishing, habitat destruction, destructive fishing practices, pollution, high export demand and high mortality of captured fry. Examples of such capture-based aquaculture include tuna (*Thunnus* spp.) in Australia, Japan, Canada, Spain, Mexico, Croatia, Italy, Malta, Morocco and Turkey; milkfish (*Chanos chanos*) in the Philippines, Sri Lanka and Indonesia; eels (*Anguilla* spp.) in Asia, Europe, Australia, and North America; grouper (*Epinephelus* spp.) in Asia; and settlement phase reef fish for the marine aquarium trade (Ahmed *et al.*, 2001; Hair, Bell and Doherty, 2002; Ringuet, Muto and Raymakers, 2002; Phillips, Melville-Smith and Cheng, 2003; Miyake, Miyabe and Nakono, 2004; Ottolenghi *et al.*, 2004; Mous *et al.*, 2006).

The purpose of this paper is to review the social and economic impacts of capture-based aquaculture, and specifically the capture of ELP animals from the wild for use as seed material in marine and freshwater grow-out. The considerations and impacts highlight the overlap of capture fisheries and aquaculture in capture-based aquaculture. Markets have been the driving force behind the development of the capture-based aquaculture industry as the selection of species for culture reflects demand in local and international markets, and consumer’s tastes and preferences. Other economic issues include costs and profitability (private and social), market channels, and externalities. Social issues include employment, livelihoods, rural development, property rights, conflicts, technology, culture/traditions, ethical opinions and public participation. These issues and their impacts will be discussed in this paper.

THE ROLE OF CAPTURE-BASED AQUACULTURE IN AQUACULTURE PRODUCTION

The system of aquaculture production called capture-based aquaculture has differing characteristics and techniques depending upon the area of the world and species. The use of this aquaculture practice is constantly evolving as demand and technology change.

Use of wild seed for capture-based aquaculture

Aquaculture with seed harvested from the wild is practiced worldwide on a variety of marine and freshwater species. Due to lack of reporting and statistics, it is extremely difficult to make an accurate estimate of the scale of such practices or the percentage of aquaculture production in the freshwater and marine environment which is reliant on the capture of ELP animals from the wild. FAO (2006) has estimated that 20 percent of marine aquaculture production comes from such capture-based aquaculture representing a value of US\$1.7 billion. The culture of many freshwater

species also relies partly or fully on wild seed because the supply from hatcheries is not adequate to meet demand or because the quality of hatchery produced seed is felt to be inferior to wild caught seed. No estimate has been made for freshwater capture-based aquaculture production. Reports suggest that there is increasingly more use of hatchery-reared seed for many species as the technology improves and due to the diminishing supply of wild seed. The lack of a stable wild seed supply has been a significant obstacle to the further expansion and development of many aquaculture species. The changing nature of seed supply in aquaculture, from wild to hatchery-produced, adds to the complexity of developing an accurate estimate of reliance of aquaculture on wild caught seed.

While accurate figures on the scale of capture-based aquaculture are not available, a number of papers and reports from around the world provide estimates for individual species which illustrates aquaculture's continued reliance on wild caught seed. It has been reported that for some freshwater species, such as omnivorous river catfish (*Pangasianodon hypophthalmus*) and carnivorous giant snakehead (*Channa micropeltes*) in Cambodia, that all of the seed is obtained from the wild (APFIC, 2005). In the Philippines, while hatcheries are becoming an increasingly more important source of milkfish fry, Ahmed *et al.*, (2001) estimated that the hatcheries are only supplying approximately 15 to 20 percent of the demand. Although many species of bivalves are routinely produced in hatcheries, the scale of wild spat collection often dwarfs hatchery production (Hair, Bell and Doherty, 2002). It is estimated that up to 95 percent of mussel (Mytilidae) spat is collected from the wild; approximately 15–20 percent of edible oysters (Osteridae); and approximately 50 percent of scallops (Pectenidae). The production of spiny lobsters (mainly *Panulirus ornatus*) in Asia (China, India, Malaysia, Myanmar, Philippines, Singapore, Taiwan Province of China, Thailand, Viet Nam) is based mainly on the capture of wild juveniles (Hair, Bell and Doherty, 2002; Tuan and Hambrey, 2000). Although hatchery-reared groupers are available, wild-caught juveniles remain the primary source of seed for aquaculture of these species in Asia (Sadovy and Vincent, 2002). Approximately one half to two-thirds of the regional supply of grouper comes from wild-caught adult fish. Major sources of wild-caught grouper are the Philippines, Indonesia, Thailand, and Malaysia. In addition, Australia, Viet Nam, Myanmar, Papua New Guinea and China also supply wild-caught grouper. New supply sources include remote islands in the Indo-Pacific such as Micronesia (Federal State of), Maldives, Solomon Islands, Fiji and Kiribati (Pomeroy, Parks and Balboa, 2006). In Viet Nam, the giant freshwater prawn *Macrobrachium rosenbergii*, which is indigenous to the Mekong Delta, is becoming an increasingly important cultured species. The culture of this species, especially in rice fields, is based mainly on wild seed collected from rivers and other freshwater bodies (Phuong *et al.*, 2006). The seed for sand goby culture in Viet Nam is obtained primarily from the wild (Phillips, 2002). While not for food, ornamental fish production is an important component of the worldwide aquaculture industry in several nations. Most of the aquaculture production of ornamental fish focuses on freshwater species. Approximately 90 percent of freshwater ornamental fish are captive bred (Bartley, 2000). While marine ornamentals capture higher price, their captive breeding and culture is much less advanced. Only 100 of 800 marine species traded in the pet industry are routinely bred in captivity, with approximately 21 of these being commercially feasible (Tlusty, 2002). As can be seen, many important cultured species still rely on the use of wild organisms as seed material.

Historical perspective on capture-based aquaculture

A variety of species groups and aquaculture production systems that have evolved based on the collection of gravid females or wild-caught seed show that harvest occurs at life history stages ranging from planktonic (pre-settlement) post-larvae to

large juveniles. This historical evolution is changing for many species and production systems, however, as the harvest of wild seed has often been unsustainable and unable to support higher production demands as hatchery produced seed has become more available and of higher quality and less expensive. In many cases, the technological progress in hatchery technology has displaced capture-based aquaculture as a source of seed. The following discussion highlights the historical and technological shifts occurring in the culture of many species which were once fully dependent upon wild caught seed.

In Viet Nam, before 1997, the supply of “Tra/Basa” fingerlings relied on wild seed. Recent successes in *Pangasius* breeding (*Pangasianodon hypophthalmus* and *Pangasius boucourti*) have led to more farmers stocking hatchery-reared catfish. About three billion fry were produced in 2004. High seasonal demand for the fry led to an insufficient supply. From the end of 2003 to the beginning of 2005, the price of fry increased two fold. There is concern that the multi-breeding of broodstock in the hatcheries has led to lower quality of fish seed (Sinh, 2005). Increasingly in the Mekong Delta, prawns are coming from hatcheries, as demand for post-larvae rises. Whether this is because of diminishing wild supply, or high demand, or a combination of both, is not known. From the limited information available, there appears to be no evidence that juvenile collection is a wasteful use of the resource, although other species are discarded in the process (Phillips, 2002).

Collection of seed, in particular shrimp seed, involved a significant bycatch of larval fish and crustaceans that was discarded, further damaging wild stocks. Larsson, Folke and Kautsky (1994) estimated that 872–2 300 km² of mangrove was required to supply post-larvae to Colombia shrimp farms in 1990, equating to 20–50 percent of the countries mangrove forest. In response, state-run hatcheries, often supported with external assistance, were established to supply seed to emerging aquaculture sectors, however, in many cases these hatcheries were often poorly managed, producing low numbers of poor quality seed; furthermore, production cycles were often poorly matched to farmers needs and the timely distribution of seed was problematic (Bunting, 2006).

In Bangladesh, the demand for shrimp fry increased with the rapid expansion of the shrimp industry after the mid-1980s. According to the Department of Fisheries, there are 40 *Upazilas* (sub-districts) under 12 coastal districts along the 710 km long coastal area where shrimp fry are collected (DOF, 2004). The increased fishing pressure on the fry fishery has long been thought to be contributing to the gradual decline in abundance and distribution of mother shrimp causing serious damage to the productivity of coastal and marine fisheries. Moreover, a huge number of eggs, larvae and juveniles of non-target fish and shrimp harvested during shrimp fry collection are included in the bycatch. Overfishing of these fisheries has occurred to the extent that fishing in the artisanal sector is no longer remunerative. The penaeid shrimp stock in particular is over-exploited in all three fisheries, but the fry fishery in particular removes an estimated 90 percent of the *Panaeus monodon* fry stock.

Mud crab aquaculture has been practiced for many years in Southeast Asia, based primarily on capture and fattening of juvenile crabs from the wild. There is an unmet demand for mud crabs and this has led to over-exploitation in many areas. Difficulties with obtaining wild caught juveniles for farming operations, plus concerns of further over-exploitation, have led to major investment in research into hatchery techniques. Of the four species of mud crabs (*Scylla serrata*, *Scylla paramamosain*, *Scylla tranquebarica* and *Scylla olivacea*), hatchery technology is only being developed or researched for *S. serrata* and *S. paramamosain* (Allen and Fielder, 2003).

In Cambodia, traditional cage culture first developed as an activity integrated with fisheries rather than agriculture, possibly more than a century ago. It subsequently spread to Thailand, Viet Nam and, more recently, to the Lao People's Democratic

Republic. Older literature sometimes states that it is indigenous to Thailand but mentions Siem Riep province, previously in Siam but now in Cambodia. The traditional and intensive cage culture of the region developed in association with the “live boats” of fishers which have water-filled holds used to hold and transport the catch. Initially, it was entirely dependent upon wild fish both as seed and feed. Integration may also be at the livelihood level, as cage farmers, especially small-scale ones, may also be fishers and collect their own seed and feed (So *et al.*, 2005). The most important fish species in Cambodia’s cage culture system is the strictly carnivorous giant snakehead (*Channa micropeltes*). Supply of giant snakehead seed for cage culture mainly depends on the seasonal wild seed availability in the floodplains of the Great Lake using scoop nets (So *et al.*, 2005). Pond aquaculture has developed gradually in Cambodia in the last decade. Two major fish species, the omnivorous river catfish (*Pangasianodon hypophthalmus*) and the carnivorous hybrid clariid catfish (*Clarias batrachus* and *Clarias gariepinus*) are stocked in ponds. Wild river catfish seed are collected by both the farmers and fishers from fishing lots, bag net or *dai*, and other small-scale fishing grounds in the Great Lake, Tonle Sap, Mekong and Bassac rivers; while hatchery hybrid catfish seed is imported from Viet Nam (So *et al.*, 2005).

Ahmed *et al.* (2001), reporting on the results of an assessment of milkfish fry in the Philippines state that there is a strong perception among the fry gatherers that milkfish fry production from natural stocks is declining. The reasons given for the decline are: pollution, loss or degradation of coastal habitats, overexploitation of fishery resources and a decline in the *sabalo* (fully grown milkfish) population. Data generated by the study based on a one-year catch monitoring record show a declining trend in catch during both peak and lean months when compared to the historic data for the same site. On the other hand, Ahmed *et al.* (2001) found that there are indications of a growing demand for fry in recent years. This is attributable to two factors. The first is a shift from traditional or extensive culture systems to semi-intensive and intensive or high-density culture systems. The second is the shift from prawn farming to milkfish farming. This shift is due to the collapse of the prawn farming industry. It was concluded that fry availability from the wild is highly seasonal and its abundance fluctuates over time and space. The natural supply is unable to cope with the year round demand for fry for grow-out operations, even though the producers use various mechanisms (e.g. stunting the fry in nurseries or staggering the production cycle) to even out the gaps in the supply of fry. This indicates a need to develop a framework for monitoring natural fry resources and to develop greater local participation over the management of fry gathering activities. Hatcheries are seen as an increasingly important source of supply of fry for milkfish aquaculture. While the supply from the wild is decreasing, hatcheries are improving their technology for fry and fingerling production. This could mean competition for fry gatherers. Most milkfish producers, however, place a higher value on wild caught fry relative to hatchery-bred, so there is still a good market for the fry from the wild.

The live reef food fish (LRFF) trade, primarily consisting of groupers (Serranidae), wrasses (Labridae) and snappers (Lutjanidae), markets live fish for consumption in restaurants and markets, largely in Asia. Fish are supplied from capture of market sized fish, full-cycle mariculture, and grow-out from wild seed. Most live fish for the LRFF trade are currently wild-caught due to the limited supply from full-cycle mariculture. It is estimated that hundreds of millions of wild-caught seed fish are traded annually to supply grow-out operations, primarily from Thailand, Philippines and Indonesia. Only a small proportion of species desired in the LRFF trade can be hatchery-reared, with several important species still sourced exclusively from the wild. The latter include the coral trout, *Plectropomus leopardus*, the squaretailed coral grouper, *P. areolatus*, the camouflage grouper, *Epinephelus polyphekadion*, and the humphead wrasse, *Cheilinus undulates* (Sadovy, Donaldson and Graham, 2003; Pomeroy, 2007).

Carp-based aquaculture, which continues to dominate inland aquaculture in Asia, in the past tended to be limited to areas close to wild seed supplies. This may explain the tendency for fish seed production to be concentrated close to the rivers where hatchlings were harvested. The development and adoption of modern hatchery technologies and additional species has begun to change the nature of fish seed supply but the distribution of private sector hatchery and nursery operates often remain clustered (Edwards, Little and Demaine, 2002).

There is continued interest in developing methods for new ornamental freshwater species as well as advancing the culture of marine species. Size selectivity and sex selectivity in the marine ornamentals trade is a concern. For many species, juveniles and sub-adults are more desirable than adults due to their coloration patterns and their more suitable size for home aquaria (Job, 2005). Culture of ornamental fish and invertebrates is now recognized as a feasible alternative to a wild harvest of specimens. Many collecting localities currently limit either the number of fish or the number of species taken, or both. A long history of destructive collecting practices, combined with poor husbandry after collection, has damaged the long term health of reefs with subsequent negative impacts on the potential for harvesting animals and the associated economic benefits of this harvest. Cultivation can help sustain the ornamental fish industry, restore exploited and impacted wild populations and minimize future use conflicts. In addition, mounting pressure from conservation groups and governments restricts the collection of wild organisms which leaves aquaculture as the only means to satisfy market demand for these products (Tlustý, 2002).

SOCIAL IMPACTS

In many situations, and especially in developing countries, the collection and grow-out of juveniles present more socio-economic advantages than hatchery-based aquaculture since the collection and sale of juveniles to grow-out operators can provide employment and income for sectors of the population that are otherwise not able to participate in the aquaculture industry. This is especially important where advanced technology and expensive hatcheries are limited. In addition, capture-based aquaculture can support rural development and provide alternative or supplemental livelihoods, especially to women and children. There is also a strong relationship with the capture fisheries industry.

Ogburn and Johannes (1999) report the positive effects of collection of grouper juveniles in the Philippines, where fewer people now practice destructive fishing and where there has been a reduction in fishing pressure on wild caught adults and less targeting of spawning aggregations, which otherwise leads to overexploitation (Johannes and Riepen, 1995; Birkland, 1997). Tisdell and Poirine (2000) report that in one island group in French Polynesia a quarter of all families earn a living from the pearl industry by selling spat to larger farms. This reliance on wild spat has led to conservation of adults to ensure continued supply of oysters, and provided a model for other nations in the Pacific which have begun to conserve wild stocks of blacklip pearl oysters to pave the way for development of their own pearl industries (Friedman, 1999). The economic returns to a Muslim community in Northeast Sumatra in Indonesia have meant that its members can now make the pilgrimage to Mecca thanks to the profits of the grouper business (Ottolenghi *et al.*, 2004). Hair *et al.* (2002) state that in response to McAllister's (1999) concerns about aquaculture depriving local fishers of their livelihood, the capture and culture of wild juveniles should actually increase the opportunities to earn income, provided the grow-out of the animals occurs in the country of harvest.

Capture-based aquaculture operations are generally located in rural areas and can make considerable contributions to rural economies. Capture-based aquaculture can result in significant economic multipliers through the economy through employment,

more diverse household livelihoods, small business development, purchase of goods and services, increases in income and food security and generation of foreign exchange. This is especially true for areas with depressed and marginal economies and limited employment opportunities, such as occurred with bluefin tuna aquaculture near Port Lincoln, Australia (Ottolenghi *et al.*, 2004). With the constant reduction in fishing opportunities, another fishery-related industry is often a welcome alternative for the existing workforce. New skills are developed for aquaculture operations, for example, specialized divers to capture and handle tuna. In addition to the actual capture of wild seed, employment opportunities are also made available in aquaculture production and marketing. Many fishers have become active partners in aquaculture activities, either as suppliers of inputs or as farmers.

On the other hand, the collection and grow-out of juveniles present a number of socio-economic disadvantages to hatchery-based aquaculture. Capture-based aquaculture can employ inappropriate technologies and skills, and users may undertake unsustainable practices to supply farmers with wild seed. Other impacts may include exclusion of the poor from participating in (by being physically removed), or enjoying the benefits of, wild seed collection and aquaculture production; resource appropriation by elites and/or politically powerful sectors; conflict and violence.

The use of wild seed puts stress on fish recruitment for the capture fisheries and on the biodiversity of the capture areas. The harvest of gravid female shrimp and post-larvae can negatively affect biodiversity by contributing to declining fish stocks. This ecological decline results in social disruptions as well. Epler (1992) states that fishers feel that the methods used to capture post-larvae shrimp in Ecuador negatively affect the finfish and crustacean fisheries because of bycatch. Cruz (1992) notes that conflicts such as these threatened relationships among community members in Mexican coastal communities. In the Solomon Islands, the introduction of the live reef food fish trade brought about three issues of highest concern to community members: the low prices paid by the company (prices were the same as, or only slightly above, the rates for dead fish); the wastage of fish, both bycatch and post-capture mortality (the fishery obtained a reputation for being wasteful of food resources, especially in remote areas where the bycatch and dead target fish could not be fully used by the villages due to the large amounts and limited consumption and/or storage ability, or due to the distances of the fishing sites from the village); and concern over the targeting of spawning aggregation sites (especially related to ownership and use-rights disputes) (Sadovy, Donaldson and Graham, 2003).

Haylor and Bland (2001) report that many negative consequences associated with aquaculture in rural development relate to a weak institutional context. These include poor coordination and coherence between sectors (e.g. Ministry of Fisheries promoting aquaculture and Ministry of Environment promoting environmental protection); unclear mandates; unclear public/private sector responsibilities; tenure, property and user right uncertainties; weak regulatory regimes and enforcement capacity; rent seeking; ineffective communication strategies; and little involvement of primary stakeholders. Without some form of intervention, short-term financial perspectives tend to dominate environmental and social issues. Thus, there is a strong case for strategic planning of aquaculture development, rather than being reactive and uncoordinated. There is also a need for a partnership between the public and private sectors to address this weak institutional context.

Marketing and credit relationships between wild seed collectors and buyers and middlemen, such as the “*suki*” patronage relationship in the Philippines and “*bertaukeh*” in Malaysia, can affect harvesting patterns and buying and selling practices, and force fry collectors to use unsustainable practices (Pomeroy and Trinidad, 1995). Collectors may over harvest certain areas to repay outstanding loans, be dictated to as to whom the seed should be sold, or be exploited by receiving lower prices for the

seed. This patronage can further contribute to the perpetuation of an oligopsonistic market structure in which each of a few buyers exerts a disproportionate influence on the market. Reporting on the live reef food fish trade, Sadovy, Donaldson and Graham (2003) state that while fishers may gain income in the short-term, in many cases they end up indebted to brokers or required to fish in a way that is incompatible with local practices and habits.

The waters from which wild seed are collected are most often considered to be open access. These waters provide multiple social, economic and environmental goods and services to local users. The harvest of wild seed does not always benefit society, as there is high wastage and dissipated economic benefits from bycatch, and can lead to a variety of user conflicts. It can also threaten traditional marine tenure arrangements and social and cultural practices and norms. Corruption and coercion may also increase. Seed collection concessions, as exist in the Philippines, privatize the resources and restrict access by certain users. In the Kei Islands in Indonesia the arrival of outside catchers for groupers saw conflicts soon develop between local fishers and the “foreign” fishing operations. These conflicts were in part over the perceived damage to the reefs from the use of cyanide, but of possibly greater significance was the villagers’ perception that the outside operators were violating local access rights. As the industry matured, conflicts and tensions developed more within the communities – fisher against fisher, family against family – over rights to fish areas and over the methods used (Sadovy, Donaldson and Graham, 2003). Conflicts can arise between collectors and other resource users such as fishers and tourism. There can be a loss of potential alternative income generating opportunities, such as scuba diving and other ecotourism related activities, with loss of biodiversity and habitat destruction. The types of conflicts and the impacts of exploitation of wild seed for aquaculture can be unpredictable and site- and species-specific.

Access to marine resources once utilized solely by small capture fishers, for example, can be opened to local and migratory wild seed collectors through capture-based aquaculture. Epler (1992) notes that the need for post-larvae shrimp has contributed to social problems which are not specifically tied to user conflicts. Coastal communities seasonally inundated with post-larval fishers do not have the resources to cope with the influx of so many newcomers. They lack adequate sanitation, education and medical facilities and there were complaints about dirty beaches and shanty towns. The economic gains to these communities are minimal as the wealth associated with shrimp mariculture returns with the transient fishers or is exported out of the country. In Bermuda, the fishing and capture-based aquaculture industries wanted to increase the quantity of fish that they were allowed to catch, in order to satisfy local demand and increase both market shares and income. However, the tourism industry wanted to decrease fishing quotas because it needs a thriving aquatic life for tourists to enjoy. By the 1980s, the stock of grouper had declined, and tourism had the upper hand (Ottolenghi *et al.*, 2004).

Padilla *et al.* (2003) conducted a community and social impact assessment to determine the relationship between the live reef fishing industry and social issues and problems. They found that the current state of the live reef fish trade in the Calamianes Islands in the Philippines is socially unsustainable. There is greater competition among fishers, both locally and from outside the area, for resources causing increased damage to the ecosystem. The fishers have a low regard for local government and national line agencies in resource management, seeing them as ineffective. Local governments are seen as being controlled by official’s vested interests and controlled by local financial and political elites. The *barangay* local government is regarded as having more significance and potential relevance than municipal or provincial governments. Fishers have little regard for their role in overall decision-making and for their relation with local government units regarding the live reef fish trade. Most fishers believe that only

local and financial elites have the capacity to make decisions. There is a high level of dependency of fishers on brokers and financiers for money which has resulted in an inequitable distribution of benefits. Live reef fishing has become the major economic activity for most of the communities in the Calamianes Islands. The dependency arrangements, inequitable distribution of benefits, growing threat to food security, limited access to basic services and weak socio-cultural cohesion in the communities is leading to a significant level of social instability.

Several case studies are presented to further illustrate the social advantages and disadvantages of capture-based aquaculture.

Case study: Philippine milkfish fry collectors

Two major studies of milkfish fry collection have been undertaken in the Philippines. One was undertaken in the early 1980s (Chong, Smith and Lizarondo, 1982) and the other in the late 1990s (Ahmed *et al.*, 2001). A brief summary of these reports provides a good description of milkfish seed collectors and collection practices.

Chong, Smith and Lizarondo (1982) found that there are a number of different passive or active filtration methods used to gather fry, ranging from the simple scissors dip-net that can easily be used by children, to the more sophisticated bulldozer net which can be operated with a motorized vessel. By far the most common method used by gatherers is *sagap*, a seine of up to five metres in length. Gatherers work in teams, the composition of which depends upon the gear used. *Sagap* requires two members to use the net, and an optional third member to carry fry from the net to a basin on shore in which fry are temporarily stored, and to sort out predators and other unwanted species. The attractiveness of the *sakag* or *hudhud* and the sweeper comes from their being easily handled by a single gatherer. Bulldozer nets are used primarily at night with lanterns and propelled by bamboo poles by a pair of gatherers at depths of up to three meters. Fry are scooped from the net with a white porcelain basin, against the background of which the eyes of the almost transparent fry can be seen. After being stored temporarily on the beach, fry are either delivered to the concessionaire, to be counted so that the gatherer can be paid for the day's catch, or stored by the gatherer for later sale. Counting fry is done by a two-member team. While fry are being temporarily stored in clay pots or plastic basins, predatory and competitive species are sorted out and discarded. Unwanted fish are most often discarded on the beach rather than returned to the sea. Revenue from the daily catch is usually divided equally among team members, with an extra share going to the owner of the gear. Most gatherers are part-time fishers, with fry gathering contributing only 22 percent to total household income. Rates of return are lowest in the fry gathering sub-sector, in comparison to fry traders and dealers, where thousands of fry gatherers participate. The low returns to fry gatherers reflect, in part, the lack of other income-generating opportunities available to them, and also the effect on fry prices of the concession arrangement. Because gatherers are restricted to selling only to the concessionaire, they receive a lower price than would prevail if there were open-access to the fry fishery and they could sell freely in the open market. One solution to this dilemma is to encourage the formation of gatherer cooperatives to be awarded concession rights for a possibly reduced fee, in which case they could earn the profits that formerly accrued to concessionaires plus a share of the resource rent.

Ahmed *et al.* (2001) found that fry gathering has been a traditional family activity for the majority of the respondents. They joined the fry gathering business through the influence of their neighbours and friends. They saw fry gathering as a lucrative additional source of income to supplement their income from other sources (i.e. fishing). In addition to fry gathering, respondents were also engaged in fishing, fish vending, daily labour, *nipa*-making and farming. About 65 percent were involved in fishing. Despite the alleged scarcity of fry in the wild, 97 percent of the respondents

did not plan to stop their involvement in fry gathering. This is probably because the activity gives them an income with little requirement of capital. During the peak season of fry demand, the average monthly income from gathering fry was approximately US\$90. During lean months, the monthly average income was approximately US\$10.

The milkfish fry of the Philippines are essentially an open access resource. The national government has empowered coastal municipalities to grant local “monopsonies” (limited to one buyer) to concessionaires in the form of exclusive rights of first purchase of fry. These concessions are generally awarded through a public bidding process. Access to fry gathering, however, is not restricted in any way, as long as the gatherer sells to the designated concessionaire. The concessionaires have two options in fry gathering: (i) to employ fry gatherers on a daily wage, or (ii) to allow the fry gatherers to use the fry grounds on the condition that 2/3 of the total catch will go to the concessionaire and the remaining 1/3 to the fry gatherers. Some concessionaires require fry gatherers to sell their share to them at a price lower than the prevailing market price. Income from the concession license fee goes directly to the municipality. Because fry grounds are, for the most part, in rural areas, municipalities with fry grounds often have very limited income from other sources. The high value of a concession compared with other components of municipal income has thus resulted in the vast majority of fry grounds in the country being managed under concession license fees. Concessionaires are free to dispose of their fry as they please provided they comply with the government auxiliary invoices required for interregional shipment of fry (Chong, Smith and Lizarondo, 1982; Ahmed *et al.*, 2001).

The concession arrangement has a major effect on the incidence of risk in the short run. Because annual bidding for concession rights is held before the fry season begins, the risks of poor catch (and windfall profits in good years) are very neatly passed from the municipality to the entrepreneur who is awarded the concession. In the long run, of course, these risks and windfalls would be taken into account by prospective concessionaires before they bid for the concession. Since the municipality collects from a single entity for each fry ground or fry zone, the risk of lost income to the municipal government, due to collection difficulties, is also much reduced. The system of awarding concessions also provides incentive for the development of new fry grounds, as the initial investment of the concessionaire is protected through a one- to three-year contract of exclusive rights granted him by the municipal council (Chong, Smith and Lizarondo, 1982). The concession arrangement severely restricts the level of competition at the early stages after fry catch due to large capital requirements to finance concession fees, especially for the most sought after fry grounds. This has encouraged vertical integration in the industry as nursery pond operators, in particular, have sought to assure supply of fry for their ponds.

Case study: Viet Nam grouper seed collectors

Tuan and Hambrey (2000) examined technical, environmental and socio-economic issues related to wild grouper seed supply in Khanh Hoa Province in Central Viet Nam. The households studied collect approximately 200 000 seed each year, mainly “black grouper”: *Epinephelus akaara*, *Epinephelus bleekeri*, *Epinephelus coioides*, *Epinephelus malabaricus*, *Epinephelus merra* and *Epinephelus sexfasciatus*. Among the fishing gears, seine net, scoop net and push net were mainly used for collecting small fish of 1–3 cm. Seine nets provided the highest yield (catch per unit effort) in terms of number of pieces per trip. For larger seed, encircling nets, used together with artificial reefs, were the most important in terms of quantity and quality of catch. The seasonality of use of different gears reflects the growth of the seed and their move to deeper water as the season progresses.

The fishers reportedly had to spend more time to catch the same amount of seed compared with previous years. Seed production appears to be in decline, as is the

capture trend for grouper in the province, and for the demersal marine finfish. The reasons for the decline of fishing production of commercial demersal marine finfish in general, and grouper in particular, include overexploitation, especially of broodstock; using harmful fishing gears such as motorized push-nets, trawling nets, dynamite, and sodium cyanide; and nursery habitat destruction. The primary buyers were nursery farmers, grow-out farmers and middlemen. The middlemen were the main buyers, and their price was up to double the fishermen's price.

The average income of collector households from seed collection was approximately US\$700 per year, and return on labour varied between US\$1–3 per day. Sadovy (2000) found that income from grouper fry/fingerling fisheries contributes 10–50 percent to the annual income of fishers, and a single fisher's income from this source can reach as much as US\$3 080 annually. In recent years, the number of collectors has decreased as some have moved to offshore fishing activities, which were funded by the central government. The fishermen prefer the new job where they can receive a higher return on labour than from collecting fry. Alternative non-fishing jobs such as aquaculture can help the fishers in lower income classes to escape from poverty. Small-scale, mainly family-run, cage culture of grouper in Khanh Hoa Province (Viet Nam) is now a significant activity, providing a relatively high return to labour compared with existing alternative activities. For the future, hatchery production will be the only way to provide sufficient seed to allow the industry to expand. The high and increasing price of seed should make hatchery production economically viable, despite its technical difficulty.

Case study: Coral reef species

A suggested alternative to the hatchery production of many coral reef species is the feasibility of harvesting pre-settlement fishes from the plankton in numbers that do not affect the replenishment of natural populations and rearing them for sale to the ornamental trade or as juveniles for grow-out (Hair, Bell and Doherty, 2002). The fact that only a small percentage of marine species that settle into nursery habitats survive to become breeding adults is a persuasive argument for using some of the settling cohort to increase productivity through grow-out in aquaculture. Responsible application of aquaculture based on animals captured from the wild will depend on capturing juveniles before they experience the severe mortality associated with settlement, limiting the catch to ensure replenishment of spawning biomass, returning sufficient juveniles to the wild to compensate fisheries targeting adults and use of capture methods that minimize bycatch of non-target species and do not damage supporting habitats. If artisanal fisheries for the capture and culture of pre-settlement fish can be established in a responsible manner, they should enhance the employment and economic opportunities for coastal communities (Hair, Bell and Doherty, 2002). Although the capture and culture of post-larvae is unlikely to meet the demand for all the tropical marine fish required by the ornamental trade, it has created important niche markets, for example, for eco-labelled specimens which increase the value of the fish caught and reared in an environmentally sustainable manner and provides economic returns to coastal villagers (Wood, 2001; Ottolenghi *et al.*, 2004).

ECONOMIC IMPACTS

As Ottolenghi *et al.* (2004) state, markets are the key drivers for capture-based aquaculture. The selection of species for culture reflects their acceptability and demand in local and international markets. Market requirements are determined primarily by people's tastes and customs. As capture-based aquaculture potentially generates higher profits than other aquaculture systems and as the market demand for the products and species cultured remains high, it is likely that efforts to promote this activity will significantly increase.

The products of capture-based aquaculture have been able to be differentiated in the market. As the availability of cultured fish has increased, consumers have become more selective about quality and food safety issues, and farmers have sought to address consumer demand. Currently, a special brand of cultured Japanese amberjack will fetch a higher price than ordinary products. Product quality is obtained by discarding second grade fish and paying special attention to handling systems to maintain freshness. Sales have been expanded in supermarkets and retail fish stores through the marketing of special brands produced by Kagawa and Kagoshima Federation of Fisheries Cooperatives, amongst others (Nakada, 2000). Greater amberjack and yellowtail amberjack are becoming more popular than Japanese amberjack because they can be kept for more than three days under refrigeration without losing any of their flavour, colour, and firmness. Currently, the demand for them exceeds supply (Nakada, 2000).

The products of capture-based aquaculture will complement, but sometimes also compete with, those supplied from capture fisheries or other aquaculture systems. This will influence price and markets. Ottolenghi *et al.* (2004) report that the impact of capture-based farmed bluefin tuna on the Japanese market has been significant. Products are of the middle quality category, and fill the gap between top (pre-spawning bluefin tuna) and lower (smaller and post-spawned bluefin tuna) qualities. The availability of capture-based farmed products has expanded the range of products available in Japan, guaranteeing middle quality at a good price. The capture-based farmed tuna have provided the consumer with a fatty meat called “*toro*”, which only rich people could have afforded before (Miyake *et al.*, 2003). Farmed tuna are now even sold in supermarkets and used in the popular, but inexpensive, “*sushi*” bars. The availability of this new category has forced prices down for both high and low quality tuna meat. The unique tuna markets of Japan, especially for tuna from capture-based aquaculture, is becoming risky for both fishermen and farmers. The high priced “*sashimi*” tuna market in 2002 has been strong, with relatively soaring demand despite the weakness of the Yen that has affected returns on investments. However, Japanese consumers have started changing their consumption habits, choosing less expensive products (de Monbrison and Guillaumie, 2003). Competition and substitution with other less expensive tuna species has already been observed in the market, with big eye (*Thunnus obesus*) and yellowfin (*Thunnus albacares*) being sold at US\$5–11/kg in Japan versus bluefin tuna sold at US\$30–60/kg.

Ottolenghi *et al.* (2004) state that the structure of the capture-based aquaculture industry may be described at a number of levels in the hierarchy of the system, from the local production scale to the macroeconomic scale of the international trade in capture-based aquaculture species. This incorporates all the aspects related to the profitability of capture-based species culture: “seed” availability, marketing from the local production level to customers (through middlemen, exporters and wholesalers) and market trends and influences. A limit to capture-based aquaculture will be the availability of the “seed” resource. From an economic point of view, a poor supply of “seed” is the greatest risk to production. For example, wild caught farm seed availability for European eels represents 50 percent of the total production costs at present, and if there is a continuing decline in availability, this will seriously affect the overall operating costs – and future profitability. In addition to seed availability, another factor affecting capture-based aquaculture will be the price of wild seed versus the price and availability of seed from hatcheries. As new hatcheries come on line, prices of seed should decline and become more available, causing a shift in source of seed for the farmer.

Phillips (2002) reports that in the case of cage culture in Cau Doc, An Giang Province, Viet Nam, the changing role of traders is of particular interest. Different trading networks supporting this cage culture emerged in parallel. The provision of small freshwater cyprinids from nearby traps reached around 1 000 tonnes per day in

the wet season. This is traded through Cau Doc town on a daily basis to feed pangasiid and snakehead being raised in the surrounding area. *Pangasius bocourti* and snakehead (*Channa* spp.) fingerlings caught in *dai* traps, mainly in Cambodia, are also sold for grow-out in cage culture operations in Viet Nam. The trading networks that supply feed fish for aquaculture appear to have developed outside the table fish networks.

So Nam and Haing Leap (2006) described the general channels of distribution of fish seed collected from the wild in Cambodia. Fishers collected fry and/or fingerlings from lakes, reservoirs and/or rivers. The fishers stocked the fish seed in *hapas* set in large earthen ponds or rivers/lakes to hold the seed. Customers for the fish seed were middlemen, licensed companies and fish farmers. The majority of sales were to middlemen or traders, who bought fingerlings from fishers for resale.

Ahmed *et al.* (2001) described the marketing of milkfish fry in the Philippines. In Sarangani and Antique, the fry catch was all purchased by the concessionaires. In Palawan, 88 percent of the catch was bought by concessionaires, while in Ilocos Norte and Bohol, gatherers could choose to sell to others. The pricing system varies, ranging from buyers dictating the price to sellers setting the price for their catch. In some cases, open bidding takes place. Fry is either picked up by the buyer, as in the case of Ilocos, Bohol, Antique, and Palawan, or delivered by the gatherers, as is the practice for Sarangani. In most cases, cash is paid on delivery. In general, fry price during lean months is higher than in the peak months. Price is relatively lower in Puerto Princessa, Philippines, and highest in Pandan, during peak months. Gatherers received the lowest price from concessionaires and the highest from dealers/brokers and runners. Gatherers in Puerto Princessa are members of the cooperative and thus received a low price while gatherers from Pandan enjoy an open access to their shoreline and could choose where to sell their catch. Fluctuations in prices are mostly attributed to the quantity of fry available in the market.

While decreased impacts to wild stocks have been hypothesized for food production aquaculture (such as declines of certain stocks, impacts on breeding populations, food web interactions, and introduction of pathogens), and can occur in ornamental production, the decreased impacts are not as dramatic as theorized. In the food production sector, wild harvests have not declined even with increasing aquaculture production (Naylor *et al.*, 2000). In the ornamental fish industry, breeders (particularly those of cichlids) utilize wild stock every two to three generations (Dawes, 2001), thus there is a continued dependence on wild stocks. One of the main arguments against aquacultural production of seahorses (*Hippocampus* spp.) is that captive culture relies heavily on repeated removals of wild animals and thus, provides no net benefit to wild seahorse populations (Tlusty, 2002).

Capture-based aquaculture may develop or be constrained by the level of technology and investment. Grouper culture can be small-scale and family-owned and operated, while tuna culture is high tech and requires considerable investment, often by larger companies in partnership with local partners. Successful examples of where small-scale finfish culture has benefited poor coastal communities exist in Tubigon, Bohol, Philippines, where the small-scale cage culture of grouper was introduced by local government as an alternative to destructive fishing practices. There are now 141 grouper farmers organized into nine groups throughout several villages (Gonzales, 2006). Another Philippine example is the so-called "backyard type of grouper culture" such as in Day-asan, Surigao City. Here each farmer owns between two and four 3x3 m cages, each stocked with around 100 fish. These are fed wild caught fish as feed and cultured for a period of five to six months. Production costs are estimated at US\$3.88 per kilogram, with farmers claiming it is more profitable than more familiar livelihoods such as backyard pig production. The average selling price ranges from US\$7.77–19.42 per kilogram depending on the type of grouper and season. There are questions about the sustainability of this system due to the dependence on wild caught fish for feed (Gonzales, 2006).

However, there are also many potential constraints to finfish culture and its suitability as an alternative livelihood for poor fishers. These include the high-technology, capital-intensive and long term payback characteristics of finfish farming, and the difficulty of uptake of mariculture, including breaking the cycle of debt among poor fishers, and persuading people to change vocations (Haylor *et al.*, 2003). The development of small-scale or backyard hatcheries, however, can help alleviate this risk and still involve poor stakeholders in mariculture activities (Gonzales, 2006). Small-scale hatcheries are those where the capital costs are relatively low, technologies are accessible, and which focus on the larval rearing and nursery aspects of fingerling production. They do not hold broodstock; instead they purchase fertilized eggs from larger hatcheries. They offer the advantages of low capital costs, simple construction, ease of operation and management, flexibility and use for a range of marine fish species, and they offer quick economic returns (Sim *et al.*, 2005).

In the Ilocos region of the Philippines, where the milkfish industry is concentrated, the production costs per cage are reported as US\$23 504, although a profit of just over US\$3 000 is expected (Gonzales, 2006). Such high costs have deterred small-scale fishers from investing in these technologies and the cages are owned by wealthier individuals (Gonzales, 2006).

A financial feasibility analysis for the culture of *E. coioides* and *E. malabaricus* in the Philippines provided financial information on individual broodstock, hatchery/nursery, and grow-out stages and for an integrated broodstock/hatchery/nursery/grow-out system (Pomeroy, Parks and Balboa, 2006). The findings of the analysis indicate that, based on the assumptions, all four scenarios are financially feasible. However, the capital requirements for the broodstock, hatchery/nursery, and integrated system may be beyond the financial means of many small producers. A broodstock and hatchery/nursery system in the Philippines has capital investment costs of US\$68 400. The capital investment requirements for grow-out (not including purchase of transport boxes) would be US\$1 470 in the Philippines and is within the financial means of small producers. The high cost of transport boxes (200 boxes at US\$4 000) is a potential problem for the small producer, but could be shared with the fish buyer or the fish buyer could provide the boxes. A 6 cm fry in the Philippines cost US\$0.23 to produce. This compares to an average price in the Philippines in 2002 of US\$0.36–0.50 for a 6 cm fry caught from the wild. Seed cost was approximately 19–26 percent of total costs in grouper culture, depending upon stocking rate.

A financial feasibility analysis for the culture of the humpback grouper (*Cromileptes altivelis*) in Indonesia provided financial information on individual broodstock, hatchery/nursery, and grow-out stages (Pomeroy, Parks and Balboa, 2006). The findings of the analysis indicate that, based on the assumptions, all three scenarios are financially feasible. However, the capital requirements for the broodstock and medium-size hatchery/nursery scenarios may be beyond the financial means of many small producers. The broodstock scenario has capital investment costs of US\$15 366 and a medium-size hatchery/nursery scenario of US\$38 795. The small-size hatchery/nursery scenario has approximately one-tenth the capital investment cost (US\$3 258) of a medium-size scenario. The capital investment cost for grow-out (US\$1 010) (not including purchase of transport boxes) is within the financial means of many small producers. The high cost of transport boxes (200 boxes at US\$4 000) is a potential problem for the small producer, but could be shared with the fish buyer or the fish buyer could provide the boxes. The total cost per 5 cm fry from the hatchery/nursery (medium-size: US\$0.26 and small-scale: US\$0.23) was less than the average selling price in Indonesia in 2002 of US\$0.82 and the average price of US\$0.49 for a 5 cm fry caught from the wild. Seed cost was approximately 50 percent of total costs in grouper culture.

In Thailand, revenue and profit of grouper capture-based aquaculture has average annual total production costs per farm of US\$5 000, while the gross revenue was

US\$9 800, giving a net profit of US\$4 800 to the farmer, with a 96 percent rate of return (net profit/total cost). Feed accounted for 57 percent of culturing costs, whereas “seed” accounted for 24 percent. Other costs (opportunity, depreciation, repairs, etc.) accounted for 19 percent (Boonchuwong and Lawapong, 2002).

The market for glass eels for direct human consumption is one of the main competitive problems affecting the availability of eel “seed” for capture-based aquaculture, since it forces the prices of glass eels upwards. Seed costs can be as much as 50 percent of the total production costs and in the future could limit the profitability of the eel farming industry. For example, American glass eel prices in the United States of America rose over 500 percent between 1994 and 1998. In the past 20 years, prices for live glass eels have been as high as US\$2 000/kilogram, and this lucrative new market potential has been attractive to many countries, triggering a global eel industry. The market is not quite so lucrative now, due to the recent slump in the Asian economies and a slight recovery of native eel stocks (Tibbetts, Lall and Anderson, 2001).

The direct effect of the collection of wild seed – overfishing, bycatch and discards, ecological disturbance and habitat destruction – will lead to a conflict between short-term private economic benefits and longer term economic losses to society. Economic theory makes it possible to treat environmental externalities as economic externalities and to validate costs and benefits in money terms to different groups as part of an economic analysis. Environmental externalities may include obtaining fry for stocking from wild stocks. Capture-based aquaculture can serve as a good example in estimating environmental sustainability by evaluating each of the various sub-activities in relation to their resource use. If, for example, seed collection is operating at a level that permits sustainable use of the underlying resources, then the activity is environmentally sustainable. If seed collection is undertaken in a non-sustainable manner (e.g. large amounts of bycatch), substitution may be possible only for small-scale systems as the overall recruitment depends on large areas and is not hampered in principle. The collection and use of wild seed for capture-based aquaculture has implications in terms of economic values gained and lost. These losses have not been quantified to date but could be significant and far greater than the profits earned by those in the capture-based aquaculture industry. It will be important to assess capture-based aquaculture in terms of both its overall economic efficiency and its distributional implications.

Although growth and diversification in farmed marine finfish species generate certain benefits to the aquaculture industry, governments (in the form of foreign exchange earnings) and consumers (in terms of a wider selection of seafood products at lower prices), there are also ecological and resource costs. In contrast to the majority of freshwater farming systems, almost all aquaculture production of diadromous and marine finfish species is dependent on capture fisheries for essential inputs, such as seed and feed. The increased production from the culture of juveniles should at least offset any loss in yield from the wild stocks, and collection should not affect wild populations negatively or disadvantage other users of the resource. As this segment of the aquaculture industry continues to expand to satisfy market demand, more pressure will likely be placed on marine ecosystems and, subsequently, more pressure will be placed on the industry to undertake sustainable practices from environmental groups and governments.

The future of capture-based aquaculture will be influenced by improving the environmental sustainability of aquaculture through the use of market-based approaches, including the certification of products produced by sustainable means, and the ecolabelling of products from certified farms. The intention is to use the power of markets as an incentive to induce more sustainable aquaculture and to highlight the products to consumers.

Case study: Live reef fish, specifically groupers, in Palawan and the Calamianes Islands, Philippines

A case study of grouper in the Philippines further describes the role of economics and markets in driving capture-based aquaculture.

In many Asian regions, there is a focus on the capture-based aquaculture of groupers. Globally the grouper market is not large and the market demand/supply relationship can seriously influence prices, making it very sensitive due to the high exclusivity of the product (Svennevig, 2002). In Asia, there was a falling market trend (1995–1999) in the consumption of live seafood (Pawiro, 2002), especially for high-value species such as grouper. The markets for “luxury food items” such as live fish is determined by the strength of the economy, in particular the level of disposable incomes, and the prevailing exchange rate between the exporting and the importing country.

The economics of marketing capture-based aquaculture products in Asia, such as live grouper, functions at two levels, namely local and export. The local level involves the collectors and brokers. Collectors, either in the local area or from the region, are responsible for the collection of fish from the local small-scale farmers for the market. Brokers are responsible for the monitoring and movement of prices, informing farmers, and contacting collectors and wholesalers. The export level consists of marketing involving agencies or network companies. The marketing margin (the difference between the purchasing price and the selling price after the deduction of sales costs) for exporters is much higher than that for the collectors, even though the sales costs of exporters are higher. Boonchuwong and Lawapong (2002) calculated that the rate of return on total costs was as high as 94.4 percent for exporters and 49.2 percent for collectors. Exporters receive the highest returns of all traders involved in the live grouper marketing system, as they must carry all of the risks during the collection and export of the live fish – fish deaths, damage, packaging and other export costs.

While the live reef fish trade (LRFT) operates throughout the Philippines, the Calamianes Group of Islands in the northern part of Palawan is the centre of the live food fish trade fishery. According to Padilla *et al.* (2003), “Initially, fishermen from the distant provinces of Surigao, Bohol and Leyte were brought to the area to fish and to train locals in catching live fish. The activity slowly grew among fishing communities. Fish soon replaced lobster as the main live aquatic product in trade. By late 1990s, 60–70 percent of fishing communities were engaged in live reef fish collection”. It is estimated that there are about 1 000 fishers that target live reef fish. Over time, hook and line replaced fish traps. Many fishers eventually shifted to using cyanide. It is estimated that up to 50 percent of the fishers use cyanide. There are three categories of fishers operating in the area: (1) fishers who own their own boat and sell their fish to a dealer offering the highest price; (2) fishers who own their own boat but because of debt are obliged to sell to a certain dealer and accept the price offered; and (3) fishers who work on boats owned by dealers (about 80 percent of the fishers).

The live food fish trade in the Calamianes is characterized by dynamic arrangements between and among fishers, boat owners/operators, traders/middlepersons, financiers, and exporters. Most of the LRFF trade middlepersons in the area own multiple boats. Fishers are often indebted to them in a *suki* (regular customer) relationship. Transactions take place in four geographical stages – in the islands, in the town of Coron, in Manila and eventually in China Hong Kong Special Administrative Region (Padilla *et al.*, 2003). The majority of fish are shipped by air to Manila. Most live fish in the Calamianes are held in indoor “aquarium” tanks. Only undersized fish are impounded in floating cages.

Although the live reef food fish trade has been operating for several decades, economic and trade information is scant. Price and volume data are collected and reported by municipality in Palawan Province by the Palawan Council for Sustainable Development (PCSD) and the Palawan Provincial Fishery Office, BFAR-Region

TABLE 1
Quantity and value of exports of live grouper, Philippines, 1991–2004

Year	Quantity (kg)	FOB Value (US\$)
1991	1 001 846	970 367
1992	2 285 691	2 008 005
1993	5 657 325	4 472 150
1994	5 328 763	4 521 186
1995	5 819 857	4 857 583
1996	3 062 569	2 674 603
1997	3 638 577	4 166 669
1998	3 298 647	4 335 509
1999	3 720 907	4 622 687
2000	7 070 842	14 344 337
2001	5 153 767	12 045 944
2002	6 789 883	10 916 245
2003	6 819 413	9 186 614
2004	5 497 699	7 557 375

Source: National Statistics Office and Bureau of Agricultural Statistics, Quezon City, Philippines.

No. IV-B. PCSD reports on key status indicators by municipality for the live reef fish for food industry such as reef status, total production, shipment, number of accredited actors in the industry and cyanide detection test incidence.

Export data on a national level is collected and reported by the National Statistics Office and the Bureau of Agricultural Statistics. The quantity and value of exports of live grouper from 1991 to 2004 are reported in Table 1.

The imports of live grouper into China Hong Kong SAR from the Philippines was 1 200 963 kg (10.25 percent of all live grouper imports) in 2001, 1 425 664 (12.52 percent) in 2002 and 1 578 384 (13.27 percent) in 2003. The leopard coral trout and the green grouper were the two top imported live grouper species into China Hong Kong SAR.

Prices paid to the fisher or fishing company that caught the fish are generally in the range of 2–4 times the prices paid for the same fish when dead. Higher-value fish are usually graded as undersize (<500 g), good or “plate” size (500 g to 1 kg), oversize (>1 kg), or per piece (>1.5 kg). In the Philippines, where size limits are not enforced or not in place, all fish are purchased and fish that are undersize or not ready for market are moved to grow-out cages where they are held until they reach plate size.

Two characteristics of the trade are its volatility and its geographic expansion. Prices and consumption vary substantially by season, especially with the arrival of important holidays in consuming countries. Prices in Coron, Philippines, for example, peak in December–February, with lower prices occurring during April–August. Less predictable factors that have strongly impacted demand in recent years have been the state of the economy; the occurrence of health issues, such as ciguatera; and the occurrence of red tides in the vicinity of fish holding and culture facilities. Fisheries have started and stopped several times in source countries for various reasons, including decisions by governments and communities, and civil unrest. Traders are constantly seeking new sources of fish and the frontier of the fishery has continually expanded in the last 25 years (Graham, 2001).

Muldoon, Peterson and Johnston (2004) reported that in general the market for LRFF has contracted over the past five years, becoming more focused on fewer species (primarily high and medium-value groupers). The following are thought to be the main causes of these shifts:

1. Overall improvements in transport technology and access to air transport that have helped to increase imports of high-value species. This has been reinforced by relative increases in operating costs for transporting fish by sea.

2. A decline of 40 percent in the LRFF market since 1998. This falling demand has led to weaker retail prices, making purchase and transport of lower-value fish unviable.
3. Increased aquaculture production of lower-value groupers in Southeast Asia from wild-caught fish. The increase in grow-out from hatchery production is seen as a positive industry development, but there is growing concern over the parallel increase in grow-out of wild-caught juveniles for market.
4. Downturn in general business because of international health scares, such as the severe acute respiratory syndrome (SARS) and ciguatera poisoning.

The decrease in the China Hong Kong SAR consumer price index from the end of 1997 to the end of 2002 was accompanied by falls in wholesale and retail prices for LRFF. There is a growing market expansion for LRFF in the China with increasing incomes. Source countries have experienced decreasing prices for LRFF in recent years, but the impact of these price declines has been mitigated by favourable exchange rates fluctuations. Padilla *et al.* (2003) reported that the Philippines has a comparative advantage in the constantly growing fish trade. The government provided a supportive trade policy environment, particularly in the export of various fish products, to harness such potential. This resulted in such economic benefits as foreign exchange earnings, jobs and higher income for those directly involved in the export industry.

Padilla *et al.* (2003) found that for the live food fish trade, the premium price on preferred size of fish results in the targeting of young and sexually immature fish, which in turn leads to recruitment overfishing. Second, the significantly higher price of live fish drives the collection of fish well beyond limit and without regard to the capacity of the stock to regenerate. Third, cheap capital from traders and exporters further fuels the fishing trade. International demand accounts largely for the unsustainable path of the industry. Traders and exporters move fishing operations in response to shifting supply in the country.

Padilla *et al.* (2003) report that economic indicators also support the result that the industry is “mining” and degrading the resource base, greatly compromising its current and future regenerative capacity. Income from fishing has been dissipated by declining catches due to overfishing and to the growing number of fishermen. Returns from capital and labour have been greatly diminished over time, despite the increase in price of fish in nominal peso terms. The reason why fishers remain in the fishery is primarily the lack of non-fishing employment alternatives in the remote islands.

Management of seed fisheries

As capture-based aquaculture is an overlap between fisheries and aquaculture, the management of the resources and the species involved must take into account the requirements of both practices. Aquaculture production methods are constantly changing with new technologies being introduced. An issue in managing capture-based aquaculture, which operates in many locations within a country, is the inadequacy of existing legislation to address the many aspects of this aquaculture practice. Countries need to create or amend the comprehensive regulatory framework to ensure that the sector develops in a sustainable manner. In most fishery management laws there are minimum sizes on harvested species, and often restrictions on the harvest of spawning adults. In some situations, governments have tried to outlaw such fisheries, but these attempts have mostly not been supported by scientific data, and have generally been unsuccessful due to inadequate enforcement (FAO, 2006). Management of seed fisheries requires a sound knowledge base and a decision-making process based on the participation of the different stakeholders.

FAO (2006) states that responsible application of aquaculture based on seed fisheries requires that juveniles are caught before they experience severe mortality, recruitment must be sufficient to ensure that fisheries targeting adults are compensated, and capture

methods must minimize bycatch of non-target species and may not damage supporting habitats.

A number of measures have been developed to manage seed fisheries:

– Many collecting localities currently limit either the number of fish or the number of species taken, or both. The Bahamian government has a limit of 50 individuals per permitted species, the Florida Keys, United States of America, has imposed size restrictions on 49 species of fish, while Brazil allows only 180 species to be exported.

– Traditionally, river catfish culture systems in Viet Nam relied entirely on wild-caught fry, with 200–800 million fry being caught annually. In the process of catching catfish fry, unwanted fry of other species were also caught, which were then discarded. This made the fishery for river catfish fry highly destructive. An estimated 5–10 kg of other fish species were killed for each kilogram of river catfish fry caught. The quantity of wild-caught river catfish fry declined tenfold in a decade because of overfishing for fry. Recognition of this problem and the successful artificial spawning of river catfish led to the banning of the fishery for wild river catfish fry in both An Giang and Dong Thap provinces in February 2000 (Trong, Hao and Griffiths, 2002).

– In the northeast region of the United States of America, dramatic declines in eel populations in the 1990s and increasing harvest pressure on all life stages prompted most states to tighten the regulatory control of these fisheries. Minimum size limits of 4–6 inches (10–15 cm) and moratoria on elver collection are now in effect. In addition, many states have gear fees, harvest locality limitations and restrictions on or banning of certain fishing gears. Stocks have begun to recover. The Queensland government in Australia manages the collection of glass eels and does not permit their export. The impact on eel fisheries globally caused by farming activities is already evident, with a decline in eel catches from 18 600 tonnes in 1994 to 12 700 tonnes in 2000 (Ottolenghi *et al.*, 2004). It is possible that the capture and export of elvers for seed may become totally banned.

– In a report on the AdriaMed Expert Consultation on interactions between aquaculture and capture fisheries (FAO, 2003), it was recommended that tools to regulate the use of wild seed/juvenile/sub-adult and adult collection for farming include quotas and licenses for collection. It was also recommended that there be the development of specific legislation to inform the consumer on the traceability of fish products.

– In 2004, the International Standard for the Trade in Live Reef Food Fish was produced. This voluntary LRFF Standard was produced through an international consultation process and covers the capture of wild live reef food fish; the aquaculture of live reef food fish; and the handling, holding distribution and marketing of live reef food fish. It is aimed at being a standard to which all responsible members of the LRFF trade will adhere so as to enable the trade to continue. The LRFF Standard aims to promote a “sustainable fishery”, i.e. one in which the harvesting of the target species is conducted in such a way, and at a rate, that 1) it does not threaten the health of the stock and the ecosystem on which it depends, or 2) it does not inhibit recovery of the stock or the ecosystem if it has previously been reduced below appropriate levels.

The Standard¹ makes specific reference to seed fisheries in section 3. Requirements of Live Reef Food Fish Aquaculture, 3.1 Management Requirements, 3.1.2 Limits to harvesting wild caught fry, fingerlings and juveniles:

- a) The harvesting of wild-caught fry and fingerlings shall occur only when it can be demonstrated that it does not damage or negatively impact the sustainability of wild stocks.
- b) Aquaculture farms that use wild-caught fry, fingerlings and juvenile must have a programme in place to eliminate their use for LRFF aquaculture.

¹ http://www.livefoodfishtrade.org/aquaculture/part1/requirement1_2/index.htm

The LRFF Standard provides interpretation of this management requirement by stating that where wild-caught fry and fingerlings are harvested, best-practices with respect to fishing gear should be adhered to so that: a) bycatch and waste are minimized, and b) mortality of target and non-target fish are minimized.

The LRFF Standard states responsible practice should include:

- Capture of pre-settlement fry/juvenile fish. Aquaculture should reduce its reliance on the capture of wild-caught reef fish to remove pressures on wild stocks. Harvesting of wild-caught fry and fingerling should only be carried out where it can be shown not to damage or affect sustainability of wild stocks.
- Reduction of post-harvest mortality. Fishing gears used in the fishery should minimize bycatch and waste and minimize the mortality of target and non-target species. Post-capture, handling and transportation practices should likewise reduce current mortality levels.
- Limits on exports of fry and fingerlings. Limits should be considered for the volume of fry and fingerlings able to be exported as well as specific measures to restrict exports of endangered species or fish which are under given minimum.
- Ongoing government endorsed research. A present lack of knowledge of the impacts of harvesting at different sizes/stages of life history, which fishing gears can reduce mortalities and mortality rates caused by capture and handling highlights the need for further research to identify best practices.
- Improve fisher and farmer awareness of current practices. There is a lack of awareness by fishers and farmers on post-harvest mortality, bycatch, and impacts of catching immature fish. This constraint calls for hands on extension and demonstration could be more effective in some cases. This manual should raise awareness of the issue of resource wastage.

– Several potential problems will need to be overcome with grouper aquaculture. The future of the industry will depend on having a regular supply of hatchery-raised seed and fry. The collection of seed and fingerlings from the wild is not sustainable in the long term and the export of wild-caught grouper seed needs to be regulated or prohibited. Cultured grouper can be certified for quality and good culture practices. Grouper grown from hatchery reared seed, as compared to wild-caught seed and fingerlings, can be certified. Sadovy (2000), in a survey of grouper fry/fingerling supply in Southeast Asia, made several recommendations in relation to the seed fishery and in respect to future development of mariculture in the region:

- 1) Prohibit all export of wild-caught grouper seed. Grouper should be cultured to market-size within the source countries.
- 2) Develop and implement careful and controlled studies on selected grouper seed fisheries in major producing areas, whereby information is integrated on catches, socioeconomics, market forces, associated adult fisheries, and habitats.
- 3) Reduce or eliminate the use of destructive (of habitat) or particularly wasteful (producing high mortality in, or damage to, target and/or non-target species) fishing gears or methods (like adding lights) and carry out studies on preferred gears to ensure that their operation does not incur greater waste or damage than is absolutely necessary.
- 4) Ensure better use of existing resources and reduce wastage of grouper seed biomass (and bycatch) arising from unnecessary mortality from harvest, transport and culture.
- 5) Examine, scientifically, the possibility of focusing the capture fishery on the smallest seed available and improve the means of nursing this phase to one suitable for widespread, small-scale culture.
- 6) Develop management approaches to protect key seed settlement and nursery habitats, such as mangrove areas and seagrasses in river mouths and estuaries,

- and protect the production of those seed by safeguarding the spawning adults (i.e. in spawning areas or spawning aggregations).
- 7) Provide government assistance both in terms of incentives, or low-interest loans, to enable small-scale fishers to enter the culture sector to produce low intensity, high quality, cultured grouper, in suitable grow-out areas, and in terms of training in post-capture handling to reduce mortalities, and in nursing.
 - 8) Develop certification systems for quality and good practice. For example, a distinction between hatchery produced and wild-caught and reared seed could provide incentives for producing good seed quality and good-quality cultured (i.e. ciguatera-free, not caught with cyanide, etc.) fish, as well as for good aquaculture practices.
 - 9) Examine the role of hatcheries in supplying grouper seed for culture.
 - 10) Promote the active application of the precautionary principle in the exploitation of grouper resources and the adoption by Asia-Pacific Economic Cooperation (APEC) member economies of the FAO Code of Conduct for Responsible Fisheries (CCRF).

– Sadovy (2000) compiled information on the status of regulation on grouper “seed” capture and exports that concern capture-based aquaculture. The People’s Republic of China limits the number of grouper seed fishers and the quantities of grouper seed captured. A license is needed for transporting marine seeds and this export is prohibited. In West Malaysia, the fishing of seed is not allowed during November and December; it is permitted during the peak season from January to April. No export of seeds smaller than 15 cm is permitted. In the Philippines, the use of scissor nets and fyke nets has been banned. The Philippines Fisheries Code of 1998 prohibits the export of seed milkfish and prawns but its application to grouper is not clear. In Penghu Island, Taiwan Province of China, fisheries are not permitted to catch any grouper seed of <6 cm. In Thailand, the use of push nets and fyke nets is limited.

– Many shrimp farmers in South and Central America, Bangladesh and India depend on wild-caught post-larvae shrimp, usually harvested by local fishers. In Bangladesh, the shrimp culture industry used to be entirely dependent on natural shrimp fry collected from coastal rivers, estuaries and mangrove areas. About 400 000 people are said to be engaged seasonally in fry collection activities, most of them are women and children. According to a recent survey by DOF (2004), there are 40 *Upazilas* (sub-districts) under 12 coastal districts along the 710 kilometres long coastal area where shrimp fry are collected. The fry collection is not their permanent or main occupation, rather it is a seasonal opportunity to earn money. Shrimp fry collection is a recent occupation in the last two decades. The demand for shrimp fry has tremendously increased with the rapid expansion of the shrimp industry after the mid-1980s. Many coastal people have taken this up as an alternative option for their livelihoods. But the increased fishing pressure to collect more fry is thought to be contributing to the gradual decline of abundance and distribution of mother shrimp and shrimp fry, thereby causing serious damage to the productivity of coastal and marine fisheries resources. Moreover, the huge numbers of bycatch, such as eggs, larvae and juveniles of non-target fish and shrimp during shrimp fry collection are mostly discarded on the land after sorting of target fry. It is reported that coastal biodiversity has been decreasing (DOF, 2004).

The Government of Bangladesh made a decision to impose a ban on shrimp fry collection (DOF, 2004). To address the issue of displaced fry collectors, the government initiated a programme on alternative livelihoods. Two groups of fry collectors (including males, females and children) were targeted. The non-migratory fry collectors live in cluster villages and slums around the *polders*. They are organized into groups by non-governmental organizations (NGOs) to provide training. The other group is migratory and used to live in temporary huts during collection season and move to other areas

when shrimp fry are less abundant. Rapid rural appraisals are being undertaken of this group by NGOs. Suggested alternative livelihood options include:

1. operation of shrimp fry nursery;
2. shrimp fry trading;
3. making fishing traps and gears;
4. operation of fish feed mills;
5. shrimp de-heading for processing;
6. crab fattening;
7. *hogla* and mat making;
8. bee keeping;
9. *coir* industry;
10. tree plantation;
11. horticulture; and
12. tailoring and knitting, etc.

– In 1966, the Japanese Fisheries Agency (JFA) imposed regulations limiting the number of amberjack fry (2.5–5 cm long called “*mojako*”) that can be caught annually for aquaculture purposes to about 40 million in order to protect the resource. Allocations are made to each prefecture by the Japan Seawater Fishery Culture Association. Each prefecture government decides on the allowable period for catching *mojako* and allots the number of fish allowed to be caught to the individual Federation of Fisheries Cooperatives in the prefecture (Ottolenghi *et al.*, 2004).

Currently, most legal frameworks do not provide for the zoning of aquaculture areas to reduce user conflicts, and for holding consultations to resolve conflicts. Zoning can control the distribution of fishing effort. Areas can be closed seasonally or permanently as protected areas. Given capacity limitations in many countries, the use of closed areas to protect juveniles and immature fish may be easier to enforce than size limits or gear restrictions (Sadovy, Donaldson and Graham, 2003). However, past conflicts seem to indicate that these approaches are not always adequate. These conflicts usually arise because rights over access and use of resources are not well defined or equitably applied. The conflicts may be minimized and resolved through sensitive application of appropriate laws and regulations and stakeholder participation.

Lack of institutional and enforcement capacity and a limited willingness on behalf of responsible authorities to impose management restrictions remain a key impediment to successfully managing seed fisheries in many countries. Conflicts of interest and corruption are common.

Codes of practice and industry standards can improve the conduct of the industry and move toward industry sustainability. Standardization results from consensus agreements reached between all players in the industry, both private and government. As described above, one such set of standards has been developed for the live reef food fish trade.

In the long term, the capture-based aquaculture of selected species of finfish may have to be prohibited, through legislation, if it is viewed as a threat to fisheries, to natural recruitment in the wild and perhaps to the very existence of certain species. Fry collectors will be displaced as a result of legislation to end seed fisheries. This could potentially have impacts on the livelihoods and incomes of hundreds of thousands of people in developing countries that rely on seed fisheries for part or all of their income. To address the issue of displaced fry collectors, a programme on alternative livelihoods may be initiated to assist households in the transition to other livelihood opportunities.

THE FUTURE OF CAPTURE-BASED AQUACULTURE

Capture-based aquaculture has social and economic advantages and disadvantages compared to full-cycle aquaculture. In many situations, especially in developing

countries, capture-based aquaculture can provide income and livelihoods to sectors of the population that may otherwise be excluded from aquaculture. However, it can also result, among others, in loss of societal benefits from the loss in yield from the wild stocks and conflict. Markets have been the driving force behind the development of capture-based aquaculture and will continue to be in the future. It is anticipated that capture-based aquaculture will continue to expand in the short-term, both for those finfish and non-fish species currently being cultured and possibly with others that may be selected for aquaculture in the future. However, the main constraint to expansion is “seed” supply. Wild seed supply has not been able to keep up with the increasing demand from farms. The capture of wild seed is being increasingly regulated. It is important that means be found to rear these species throughout their full life-cycle that are economically viable. Farmers will also need to reduce their production costs to meet changing market demands. Any future expansion of capture-based aquaculture will also need to address damage to the environment caused by its activities and regulate itself in a more sustainable manner. In all cases, there will be positive and negative social and economic impacts that will need to be managed more strategically.

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PART 2

SPECIES PAPERS

Capture-based aquaculture of Pangasiid catfishes and snakeheads in the Mekong River Basin

ANDERS POULSEN, DON GRIFFITHS, SO NAM AND NGUYEN THANH TUNG

Capture-based aquaculture of *Clarias* catfish: case study of the Santchou fishers in western Cameroon

VICTOR POUOMOGNE

Capture-based aquaculture of mullets in Egypt

MAGDY SALEH

Capture-based aquaculture of wild-caught Indian major carps in the Ganges Region of Bangladesh

MHD MOKHLESUR RAHMAN

Capture-based aquaculture of the wild European eel (*Anguilla anguilla*)

THOMAS NIELSEN AND PATRICK PROUZET

Capture-based aquaculture of bluefin tuna

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BENT M. DREYER, BJØRG H. NØSTVOLD, KJELL Ø. MIDLING AND ØYSTEIN HERMANSEN

Capture-based aquaculture of yellowtail

MAKOTO NAKADA

Capture-based aquaculture of groupers

MARK TUPPER AND NATASJA SHERIFF

Capture-based aquaculture of mud crabs (*Scylla* spp.)

COLIN SHELLEY

Oyster capture-based aquaculture in the Republic of Korea

KWANG-SIK CHOI

Capture-based aquaculture of Pangasiid catfishes and snakeheads in the Mekong River Basin

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INTRODUCTION

The Mekong River Basin is probably the largest and most important inland fisheries in the world (Figure 1). The annual yield from capture fisheries in the lower Mekong basin (encompassing the Lao People's Democratic Republic, Thailand, Cambodia and Viet Nam) is estimated at between 2.5 to 3 million tonnes, accounting for 2 percent of the total annual global fisheries yield including both marine and inland fisheries. This in turn represents a direct monetary value of approximately US\$2 000 million annually (Barlow, 2006). The main foundations for this important fishery are:

- the extreme fish diversity of the Mekong (second only to the Amazon River);
- the ecological functioning of the riverine ecosystem, including large areas of extremely productive floodplain habitats, and conservation of connectivity between habitats; and
- a population of 80 million people living within the Mekong basin, a large proportion of which participate in fisheries activities directly or indirectly.



An important feature of Mekong fisheries are their extreme seasonality. The bulk of the catch is taken during the flood season from August to December, when the water level rises and large inundated floodplains are formed in the lower sections of the basin, particularly in Cambodia and Viet Nam. This seasonal cycle means that there is a large surplus of fish during the monsoon season, whereas in the dry season, yields are comparatively low.

Local people and communities have adapted to the seasonal fluctuations in fish supply. They have for instance developed many ways to process and preserve catches during the monsoon, so that the surplus can be kept and used during the “lean” season.

Aquaculture also originally developed as a way to convert the large bulk of low-value yields from the monsoon season into high-value products that can be harvested, marketed and/or consumed at other times of the year. Throughout the basin, specialised “juvenile” fisheries have emerged, capturing various juvenile stages of high-value species during the monsoon season for later grow-out in ponds and cages.

Traditionally, aquaculture

enterprises in the Mekong Basin were capture-based. Only with the introduction of exotic aquaculture species during the second half of the twentieth century did the more conventional aquaculture operations, based on hatchery inputs, take over. As research capacities developed within the region, hatchery techniques for indigenous species such as Pangasiid catfishes were eventually developed, setting the scene for the further development of the aquaculture industry into what are now large-scale, export-oriented enterprises.

Although capture-based aquaculture of Pangasiid catfishes has developed into an important export industry and is now largely based on hatchery produced seed, many other capture-based aquaculture activities using wild seed (such as snakehead aquaculture) are still practiced as a way to alleviate fish shortages during lean seasons and/or converting seasonally abundant, low-value excess fish into a high-value harvest. Sustainability and management issues for Pangasiid catfish and snakehead fisheries and culture in the Mekong basin are very different.

The main management issues currently facing Mekong capture fisheries are habitat conversion and overfishing. The high levels of exploitation throughout the basin leave little room for expansion of the fisheries and the main challenges will therefore be to sustain current output levels. Any future increases in fisheries yields from the Mekong will thus have to come from aquaculture. However, if increased aquaculture outputs

are achieved at the expense of capture fisheries outputs, they do not represent net increases and may in some cases be counter-productive from a poverty alleviation point of view (e.g. when a resource that is important for the poor is converted to a high-value resource targeted at wealthier households).

The capture-based aquaculture systems that exist in the Mekong each have different characteristics, and management solutions will differ accordingly. Each fisheries/culture system will thus have to be assessed on a case by case basis. If appropriate management measures are taken based on valid data and information, and with the aim of ensuring sustainability, some may offer good opportunities for increased production. Sustainable catch levels may be identified (again, based on solid research information) and maintained to support the traditional ways of transferring bulk monsoon catches to off-season marketing and consumption.

This paper describes capture-based aquaculture practices of two groups of taxa in the Mekong basin, the Pangasiid catfishes and the snakeheads (Channidae). Pangasiid catfish juveniles are used throughout the lower Mekong basin but are particularly important in the Mekong delta in Viet Nam, where their culture has shifted from a traditional small-scale activity into a million-dollar export business, largely based on hatchery seed. Snakehead juveniles from the wild are used in grow-out cages, ponds and pens throughout the basin as a way to convert low-value catches from the peak monsoon season into high-value harvest in the off-season.

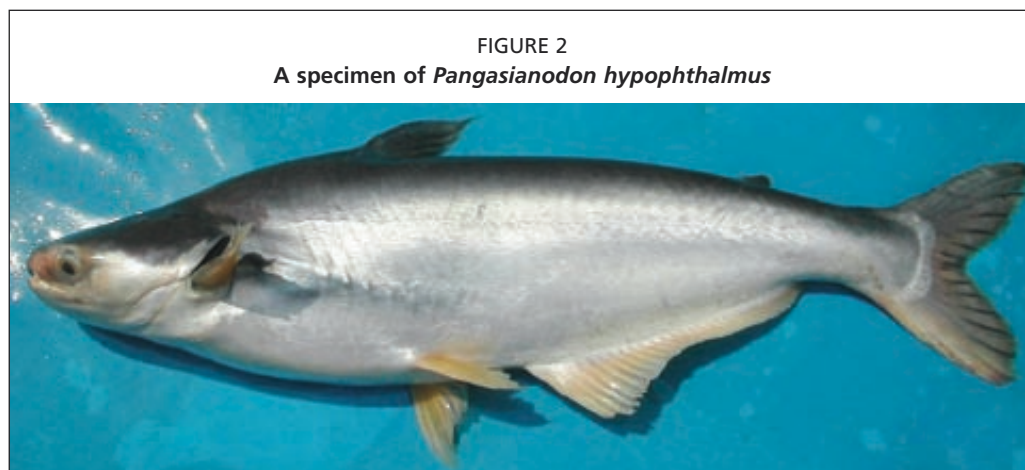
The two species groups thus represent two different development scenarios for capture-based aquaculture in the Mekong basin. In one group (the catfishes), the traditional wild seed-based aquaculture practice triggered the development of hatchery technology, allowing the aquaculture practice to shift from wild seed-based to the current hatchery-based practice. In the other group (the snakeheads), the practice has largely remained wild-seed based.

DESCRIPTION OF THE SPECIES

Pangasiid catfishes

There are 16 species of Pangasiid catfishes in the Mekong, belonging to four genera (*Helicophagus*, *Pangasianodon*, *Pangasius* and *Pteropangasius*) (Gustiano, 2003). The group include one of the largest and most conspicuous freshwater species in the world, the Mekong giant catfish (*Pangasianodon gigas*).

Only two species are currently used in significant numbers in capture-based aquaculture: the river catfish (or Sutchi catfish) (*Pangasianodon hypophthalmus*) (Figure 2) and Bocourt's catfish (*Pangasius bocourti*). Some of the others, particularly *Pangasius conchophilus*, *Pangasius krempfi* and *Pangasius larnaudiei* are also used (Trong, Hao and Griffiths, 2002), but at much smaller scales.



The traditional development of capture-based aquaculture was based on Sutchi or river catfish, *Pangasianodon hypophthalmus*, probably because it is a prolific spawner, which produces a relatively large number of larvae that are easily harvested from the flowing river. *Pangasius bocourti* on the contrary, lays far fewer eggs and thus it is harder to collect significant numbers of drifting wild fry. They are instead captured when they are older and bigger (i.e. at a total length of around 5 cm) using specialised hooks (Van Zalinge *et al.*, 2002).

All of the Pangasiid species are migratory. Some of them carry out spectacular long distance migrations between feeding habitats, refuge habitats and spawning habitats. The two key species above, for instance, both migrate several hundred kilometres between upstream refuge/spawning habitats and downstream feeding and nursery habitats.

Research programmes are currently working on the domestication and artificial breeding of several species of the group, including *Pangasius krempfi* and *Pangasius larnaudiei*, and these may become important aquaculture species in the future. However, since *Pangasianodon hypophthalmus* and *Pangasius bocourti* are the main cultured Pangasiid species in the Mekong, they are the main focus of this paper.

Life cycle of *Pangasianodon hypophthalmus*

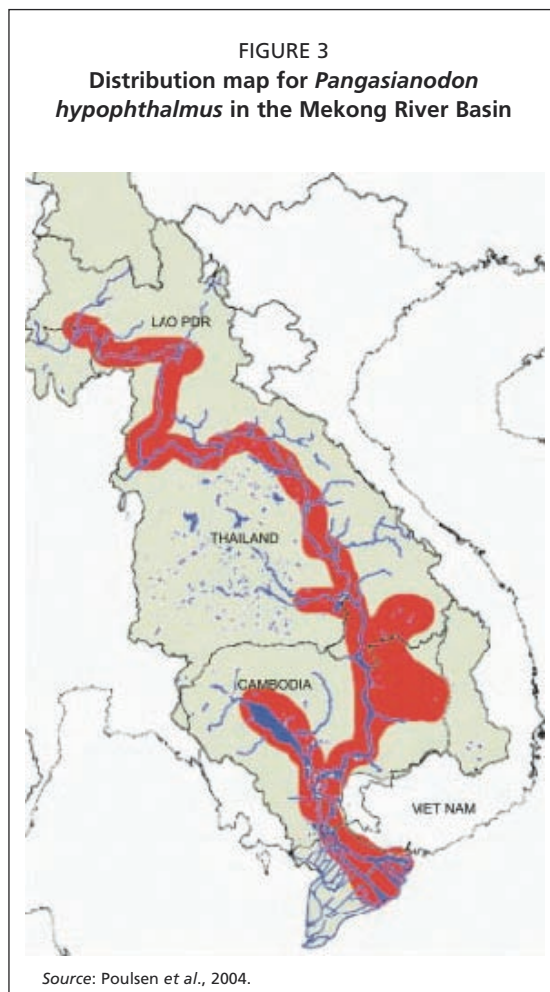
The river catfish, *Pangasianodon hypophthalmus*, occurs throughout the lower Mekong Basin, from the upper reaches along the border between Thailand and Lao People's Democratic Republic, through Cambodia, to the Mekong delta in Viet Nam (Figure 3). It is however extremely rare in the upper reaches. It has been suggested that there are two or more separate populations, i.e. a small "upper Mekong" population

(mainly covering Thailand and Lao People's Democratic Republic) and one or more "lower Mekong" population(s), mainly covering southern Lao People's Democratic Republic, Cambodia and Viet Nam, which is by far the largest population (Poulsen *et al.*, 2004), a hypothesis subsequently supported by recent genetic studies (So, Maes and Volckaert, 2006a; So, Maes and Volckaert, 2006b).

As with all other fishes of the Mekong, the life cycle of *Pangasianodon hypophthalmus* is intimately synchronized with the annual flood cycle caused by the monsoon. Spawning mainly takes place at the beginning of the monsoon in May-June. For the southern population, the main spawning grounds are believed to be located in the mainstream Mekong in northern Cambodia along a stretch between the two river towns of Kratie and Stung Treng (So, 2005). This stretch of the river is particularly rich in rapids and deep pools and is generally considered a key area for a large proportion of Mekong fishes particularly for spawning, and as a dry season refuge, including most of the Pangasiid species.

The eggs are sticky and are believed to be deposited on roots of certain types of vegetation (Touch, 2000; Van Zalinge *et al.*, 2002). A 10 kilogram individual can produce more than one million eggs (Van Zalinge *et al.*, 2002).

When hatched, the larvae enter the Mekong water column and join a large number of other



Mekong fish species in a spectacular, multi-species larval drift downstream towards the Mekong delta, where they enter their nursing grounds on the vast floodplains of the delta and Tonle Sap/Great Lake system. Studies of this larval drift in Viet Nam have identified at least 153 species of fish belonging to 32 families and 10 orders within a period of three months from May to August (Nguyen *et al.*, 2001). Subtle differences in drift patterns probably represent ecological differences between species. For instance, *Pangasianodon hypophthalmus* is the only species to mainly drift in the surface waters, which makes them easier to capture in large numbers, whereas all other species mainly occur in deeper waters (Hortle *et al.*, 2005).

Pangasianodon hypophthalmus feeds on a variety of items including algae, higher plants, zooplankton and insects. Larger river catfish also eat fruits, crustaceans and fish (Van Zalinge *et al.*, 2002).

Recent genetic studies of *Pangasianodon hypophthalmus* in Cambodia have indicated that the relatively limited extent of spawning habitats compared with the feeding habitats may have triggered the evolution of up to five “cryptic” (sympatric) populations (So, Maes and Volckaert, 2006b). These populations are believed to use the same spawning habitats, but at separate times (separate spawning “runs”) – whereas at the feeding grounds the populations are mixed (So, Maes and Volckaert, 2006b). In other words, spawning habitats may be the main bottleneck for the populations of *Pangasianodon hypophthalmus* and are therefore also of critical importance for sustaining the diversity and size of populations.

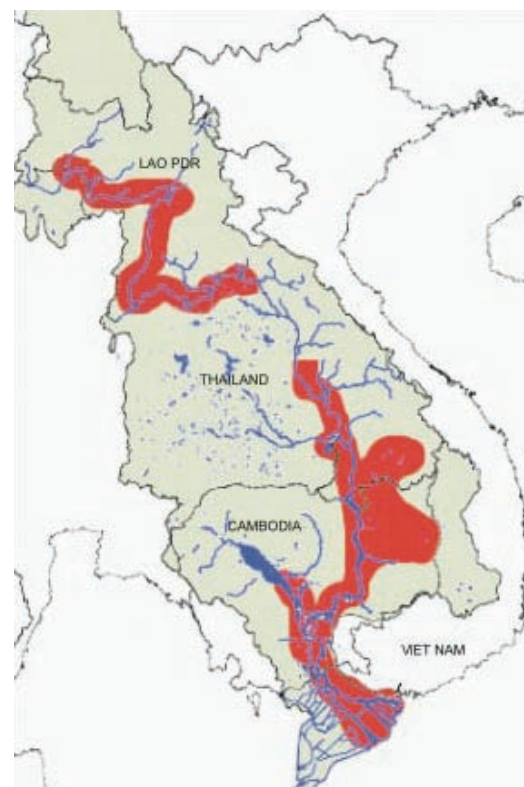
Life cycle of *Pangasius bocourti*

Pangasius bocourti has a similar distribution range to *Pangasianodon hypophthalmus*, and occurs in the Mekong mainstream and larger tributaries throughout the lower Mekong basin (Poulsen *et al.*, 2004). It also appears to consist of geographically separated and genetically distinct populations, i.e. an upstream population (in northern Thailand and Lao People’s Democratic Republic) and one or more populations downstream in southern Lao People’s Democratic Republic, Cambodia and the Mekong Delta in Viet Nam (Figure 4).

Genetic studies have recently indicated that several distinct sub-populations may exist in the lower Mekong reaches, in Cambodia and Viet Nam, i.e. similar to *Pangasianodon hypophthalmus* (So, Maes and Volckaert, 2006a; So, Maes and Volckaert, 2006b). Since it has not yet been possible to sample the earliest larval stages of *Pangasius bocourti*, genetic sub-structures are much more difficult to detect.

Little is known about the detailed ecology of the species, including its spawning behaviour and migration patterns. It is believed to spawn in the same river stretch in northern Cambodia and have similar migration patterns to *Pangasianodon hypophthalmus* (Poulsen *et al.*, 2004; So, Volckaert and Srun, 2006). As mentioned above, *Pangasius bocourti* is less fecund than *Pangasianodon hypophthalmus*. The main spawning season is also believed to be at the beginning of the monsoon

FIGURE 4
Distribution map for *Pangasius bocourti* in the Mekong River Basin



Source: Poulsen *et al.*, 2004.

season in May-July, but there are probably subtle, yet unidentified differences between the timing and habitat requirements of *Pangasius bocourti* and *Pangasianodon hypophthalmus*.

Thus, as with *Pangasianodon hypophthalmus*, the life cycle of *Pangasius bocourti* is determined by the annual hydrological cycle of the monsoon.

The fact that *Pangasius bocourti* is much less commonly found in catches from the floodplain habitats of the Tonle Sap and the Mekong delta, suggests that the species is less dependent on floodplain habitats for nursing and feeding and is probably more confined to the river channel habitats than *Pangasianodon hypophthalmus*.

SNAKEHEADS (CHANNIDAE)

Eight species of snakehead occur in the Mekong basin, all belonging to the genus *Channa*. Only two of these are currently used in significant numbers for aquaculture namely the giant snakehead (*Channa micropeltes*) and the Chevron snakehead (*Channa striata*).

Life cycle of snakeheads

Snakeheads generally live in still or slow-flowing waters throughout the Mekong basin. Contrary to the Pangasiid catfishes described above, they do not undertake long distance migrations, but instead make shorter lateral migrations between rivers and nearby floodplains, following the hydrological cycle of the monsoonal, floodplain river ecosystem.

Snakeheads are opportunistic breeders that can spawn whenever conditions are right. In the wild they normally spawn during the monsoon season, i.e. from May to September. They lay a small amount of floating eggs in a small nest made of vegetation. The male guards the nest, and later the fry – a behaviour that is used by experienced fishers to collect the fry for stocking in grow-out cages.

Chevron snakehead, *Channa striata*

The Chevron snakehead, *Channa striata*, is one of the most common fish in the lower Mekong basin (Figure 5). It is air-breathing and is able to live in very shallow waters and is therefore particularly well adapted to life in rice farming landscapes and ecosystems (Amilhat and Lorenzen, 2005). It moves seasonally between open-water, perennial habitats (lakes, swamps, rivers) and seasonal floodplain and rice field habitats, where spawning, nursing and feeding takes place during the monsoon period from May to October.

The long association with man-made habitats have in some places resulted in the emergence of habitat management interventions by rice farmers aimed at increasing the yield from Chevron snakehead fisheries, e.g. by making small perennial “trap ponds” within the rice farming ecosystem (Amilhat and Lorenzen, 2005).

FIGURE 5
A specimen of *Channa striata*



Giant snakehead, *Channa micropeltes*

The giant snakehead has a similar life cycle to the Chevron snakehead and is also distributed throughout the lower Mekong basin. It moves seasonally between perennial refuge habitats and floodplain spawning and feeding habitats.

It is particularly common in areas, where natural floodplain habitats and their connectivity to river habitats are extensive and intact. In the Mekong, the Great Lake and Tonle Sap River floodplain systems are particularly important for the giant snakehead – and this ecosystem consequently harbours the most important fishery, including capture-based aquaculture practices, for this species.

Other areas with maintained river/floodplain ecosystems include several tributary systems in Lao People's Democratic Republic and Cambodia. In Thailand, the Songkhram River is one of the last tributary systems with maintained floodplain systems – and the giant snakehead is therefore common in both adult and juvenile fisheries.

DESCRIPTION OF CAPTURE FISHERIES

General fisheries

Most of the Pangasiid catfishes are important species in capture fisheries of the Mekong basin, generally as elements of a diverse range of multi-species fisheries throughout the basin.

Pangasianodon hypophthalmus is particularly important in the fisheries of the Tonle Sap River and the Great Lake of Cambodia, for instance in the bagnet, or dai fisheries in the Tonle Sap River targeting a range of migratory fishes at the beginning of the dry season. They are also important in floodplain fisheries of the lower basin, in southern Cambodia and the Mekong delta in Viet Nam.

Larger specimens are caught sporadically in the Mekong mainstream and in the Sesan-Srepok-Sekong river systems in northern Cambodia. In the spectacular Khone Falls fisheries, targeting migratory species crossing the falls, the species is rarely encountered and is only caught extremely infrequently above the falls in Lao People's Democratic Republic and Thailand.

Pangasius bocourti are captured throughout the lower Mekong basin. In Cambodia and Viet Nam, it is much less frequently caught than *Pangasianodon hypophthalmus*. However, upstream in Lao People's Democratic Republic and Thailand, it is caught in large numbers in gillnet fisheries on the Mekong mainstream and larger tributaries, particularly during their upstream migrations at the beginning of the monsoon season.

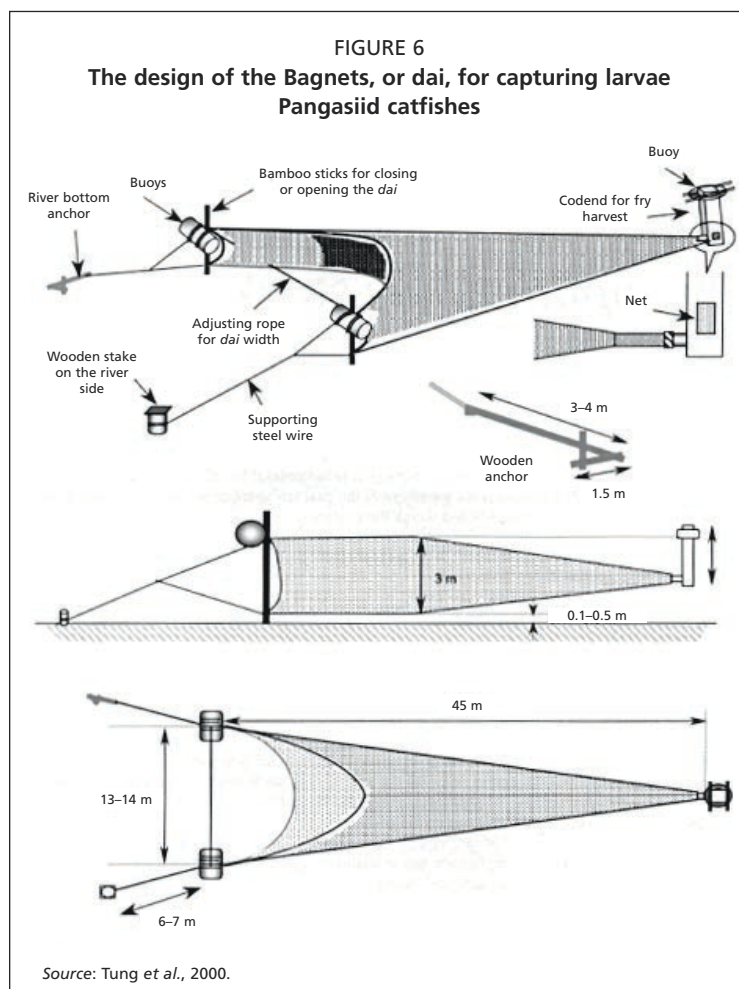
During the same period, significant numbers of *Pangasius bocourti* are also captured at the Khone Falls trap fisheries on the border between Lao People's Democratic Republic and Cambodia, when the species take part in spectacular, multispecies migrations through the falls (e.g. Baird, 1998).

Both snakehead species are extremely important in capture fisheries throughout the basin. *Channa striata* is one of the most important species in the Mekong and is mainly captured in floodplain and rice field habitats. *Channa micropeltes* is most commonly captured in sections of the river basins with maintained, natural floodplain habitats, such as the Tonle Sap River and Great Lake ecosystem and the Songkhram River in Thailand.

Capture of juvenile Pangasiid catfishes

Large numbers of river catfish larvae (*Pangasianodon hypophthalmus*) were, until recently, caught in the upper Mekong delta near the border between Viet Nam and Cambodia. The fishery was concentrated in Chao Doc and Tan Chau districts of An Giang Provinces in Viet Nam, and in Kandal province of Cambodia.

The fishery occurs over 2–3 months at the beginning of the monsoon season (May–July) when the larvae drift downstream in the Mekong mainstream towards



their nursery floodplain habitats. The spawning sites are believed to be far upstream in the Cambodian Mekong near the border with Lao People's Democratic Republic, approximately 500 kilometres from where the larvae are caught. Specialised bagnets, or dais are used, designed to enable the capture of live specimens of the tiny, fragile fish larvae (Figure 6). The dais are typically harvested 3 times daily.

Limited quantitative data are available on this fishery. Estimates from 1977 suggest that 200 to 800 million fry, 0.9–1.7 cm in length, were caught annually (based on data from An Giang Department of Agriculture, cited in Trong, Hao and Griffiths, 2002). A small amount of other Pangasiid larvae are caught in this fishery and used for grow-out, particularly *Pangasius bocourti*, *Pangasius conchophilus* and *Pangasius larnaudiei*.

In 1977, Dong Thap and An Giang province had a total of

1 974 stationary dais for the collection of river catfish larvae, of which 204 were state-owned, while 1 770 were owned by private individuals. The mean daily yield from each stationary dai was 13 100 larvae, with a total estimate of 763 million river catfish larvae being harvested in 1977 (Huy and Liem, 1977). Tung *et al.* (2000) reported a total production of 200 million river catfish larvae in 1996.

From the 1950–1980s, approximately 2 000 farmers in Hong Ngu, and Tan Chau districts of An Giang province and Chau Doc district of Dong Thap province raised wild river catfish larvae to fingerlings. The annual production of river catfish fingerlings was 50–100 million.

In the wild fishery, non-Pangasiid catfishes were either thrown back or used as fish feed (Bun 1999; Van Zalinge *et al.*, 2002). Only an estimated 5–15 percent of the larvae harvest was river catfish and an estimated 5–10 kilogram of other fish species were killed for each kilogram of river catfish fry caught (Phuong, 1998). Bycatch of non-target larvae was higher in Viet Nam than Cambodia probably because there were lower numbers of larvae within Vietnamese waters (Van Zalinge *et al.*, 2002).

Pangasius bocourti larvae that were 10–20 days old were also taken as a bycatch by the stationary dai fishery for river catfish. There is also a small, but specific hook and line fishery for *Pangasius bocourti* fingerlings of 12–15 cm length in Viet Nam between August–October. These fingerlings typically sell for VND 3 000–4 000 (approximately US\$0.19–0.25) each for use as cage aquaculture seed.

The dai fishery for catfish larvae was banned in both An Giang and Dong Thap provinces in March 2000, due to its perceived negative impacts on the wild stock of both target and non-target species (Ish and Doctor, 2005). Before the ban, the provincial authorities auctioned the fishery annually to the highest bidder.

TABLE 1
Estimated numbers of *Pangasianodon hypophthalmus* caught in the An Giang province dai fishery, Viet Nam

Year	Number of fry caught (million)	References
1977	200–800	Khanh, 1996
1994	62	Tung <i>et al.</i> , 2001b
1995	60	Tung <i>et al.</i> , 2001b
1996	56	Tung <i>et al.</i> , 2001b
1997	48	Tung <i>et al.</i> , 2001b
1998	36	Tung <i>et al.</i> , 2001b
1999	27	Tung <i>et al.</i> , 2001b
2000	0.4	Tung <i>et al.</i> , 2001b
2006	0.1 ¹	Phuong (Personal communication)

¹ Mainly in Dong Thap province

The fishery for juveniles in Cambodia was outlawed in 1994 but collection was still reported in 1998 (Edwards, Tuan and Allen, 2004). So and Haing (2006) estimated that in 2004, a total of 20 million fingerlings from a range of different species were caught from rivers for aquaculture purposes. Approximately 18 percent of these were Pangasiid catfishes, including *Pangasianodon hypophthalmus* (1.1 million), *Pangasius conchophilus* (900 000), *Pangasius bocourti* (600 000) and *Pangasius larnaudiei* (400 000) (Data based on official statistics of the Department of Fisheries, Cambodia, published in So and Haing, 2006).

Table 1 shows that there has been a massive decrease of wild-caught Pangasiid fry in An Giang province since 1977 to almost zero today following enforcement of the ban.

Unlike *Pangasianodon hypophthalmus*, *Pangasius bocourti* larvae cannot be caught in significant numbers in larvae dai nets. Larger juveniles are instead caught by specialised hooks, particularly in Cambodia.

CAPTURE OF JUVENILE SNAKEHEAD

The spawning habits of snakeheads make them relatively easy targets for fishers, who can visually identify parents guarding their offspring in the shallows of rice fields and floodplains, and then simply “scoop up” the fry with small nets. This is the main method for obtaining snakehead fry from the wild throughout the lower Mekong.

However, juvenile snakeheads are also caught in a variety of fisheries during the monsoon season. Examples include:

- River dai fisheries in Viet Nam and Cambodia;
- Floodplain fisheries using various traps, cast-nets and lift-nets in Viet Nam and Cambodia;
- Large lift-nets (operated from boats) in upper tributaries such as the Songkhram River, Thailand, and Nam Ngum, Lao People’s Democratic Republic;
- Great Lake fisheries, including various traps, seine nets, cast-nets (mainly for *Channa micropeltes*); and
- Rice field fisheries throughout the lower basin (mainly for *Channa striata*).

These are all multispecies fisheries that do not target any single species. The catches are sorted immediately after capture and snakehead juveniles kept and sold to cage culture operators (often through middlemen). Other large and high-value species are also taken for retail marketing, whereas the bulk of the catch of low-value fish is used for processing (e.g. fish sauce), livestock or aquaculture feed (including for snakehead culture).

In Cambodia, snakehead fingerlings are the most common species in juvenile fisheries. According to the 2004 official statistics from the Department of Fisheries (DOF), more than 15 million fingerlings of *Channa micropeltes* were caught in

Cambodian waters, constituting 77 percent of all captured fingerlings (So and Haing, 2006). By comparison, the number of captured *Channa striata* was insignificant (approximately 18 000).

In Thailand and Lao People's Democratic Republic, snakehead farming is also important, but no quantitative data are available on the capture of wild seed. *Channa striata* is produced in hatcheries, whereas *Channa micropeltes* is captured from wild stocks on a seasonal basis (Simon Funge-Smith, personal communication).

AQUACULTURE DEPENDENCY ON THE WILD SEED

Pangasiid catfishes

Cambodia

In Cambodia records show that aquaculture of snakeheads and Pangasiid catfishes in cages and pens developed in the tenth century when wild fish captured in the peak fishery season were held over until later in the year when fish were less abundant and prices were higher. Fish species like “trei riel” (*Cirrhinus siamensis*), mixed with rice bran were/are the main feed ingredients used to fatten snakeheads and Pangasiid catfishes. Over time aquaculture of both snakehead and Pangasiid catfishes developed and intensified with deliberate capture of juveniles of both species for culture.

Today over 80 percent of aquaculture production in Cambodia comes from cages and pens in the Great Lake and Tonle Sap, and along the Mekong and Bassac rivers. River catfish *Pangasianodon hypophthalmus* is the main fish species cultured in earthen ponds, while snakehead *Channa micropeltes* is the main cultured species in floating cages. Intensive *Pangasianodon hypophthalmus* culture, is also conducted around Phnom Penh and in Kandal province because of its close vicinity to the urban markets of Phnom Penh (Phillips, 2002).

In 2004, 26 percent of the total number of fish seed used for aquaculture in Cambodia was wild caught. Of these, *Channa micropeltes* accounted for almost 78 percent (15 million fingerlings), *Pangasianodon hypophthalmus* for 4.7 percent (1 million) and *Pangasius bocourti* for 2.3 percent (600 000). Approximately 56 percent of aquaculture seed was imported (mainly from Viet Nam), while domestic hatcheries supplied only 18 percent (So and Haing, 2006).

There are a total of 14 government hatcheries in Cambodia, though not all function well because of poor water supply systems, limited staff capacity, funding and broodstock resources (So and Haing, 2006). The 5 largest freshwater fish seed hatcheries in Cambodia are the 4 government hatcheries (Bati Fish Seed Production and Research Centre in Prey Veng province, the Chrang Chamres Fisheries Research Station, the Toul Krasang Fish Seed Production Station in Kandal province, and the Chak Ang Rae Fish Seed Production Station in Phnom Penh) and the NGO SAO-Scale hatchery in Kandal Province, near Phnom Penh.

Viet Nam

Pangasianodon hypophthalmus (“tra” in Vietnamese) and *Pangasius bocourti* (“basa” in Vietnamese) have been traditionally cultured for centuries in Viet Nam (Peignen 1993, cited by Cacot, 1999; Lazard and Cacot, 1997). Today river catfish and *Pangasius bocourti* are the two main cultured freshwater fish species in Viet Nam in terms of both quantity and export value. Like Cambodia, the Vietnamese Pangasiid aquaculture industry developed from holding fish over to sell later when supply was lower and prices were higher. Culture of Pangasiid catfishes prior to 1980 was totally dependant on stocking of wild caught seed.

Pangasianodon hypophthalmus were first artificially propagated in Thailand in 1959, and the technology has since spread throughout southeast Asia (Trong, Hao and Griffiths, 2002). The doctoral thesis (in Vietnamese) “Induced spawning of the

TABLE 2
Pangasiid larvae and fry/fingerling production (millions) by province in the Mekong Delta region of Viet Nam, 2000–2005

Province	2000		2001		2002		2003		2004		2005	
	Larvae	Fry	Larvae	Fry	Larvae	Fry	Larvae	Fry	Larvae	Fry	Larvae	Fry
An Giang	36	2	45	2	228	17	240	24	375	27	715	66
Dong Thap	430	30	416	36	572	47	624	52	4 250	935	4 681	1 744
Can Tho		–	–	19	–	9	–	4	–	3	–	3
Vinh Long				6	–	7	–	10	–	8	–	6
Tien Giang				–	–	–	–	2	–	2	–	1
Long An												
Hau Giang												
Bac Lieu												
Kien Giang												
Soc Trang												
Ca Mau												
Tra Vinh												
Ben Tre												
An Giang												
Total	466	32	461	63	800	80	864	92	4 625	975	5 396	1 820

Source: Provincial DOFI and DARD annual progress reports.

river catfish *Pangasius hypophthalmus* in the Mekong Delta” (Khanh, 1996) details the development, beginning in 1978, of artificial propagation techniques for the river catfish (*Pangasianodon hypophthalmus*) in Viet Nam. Prior to 1996, there was no hatchery production of Pangasiid catfishes in Viet Nam.

Table 2 shows the rapid rise in the hatchery production of river catfish seed in the Mekong Delta of Viet Nam, with larvae and fry/fingerling production increasing 11 and nearly 57 fold respectively, between 2000 and 2005.

In 2006 the 130 hatcheries (An Giang 15; Can Tho 5; Tien Giang 4; Vinh Long 3; and Dong Thap 103) in the Mekong Delta region of Viet Nam produced 10 billion river catfish larvae and the production of *Pangasianodon hypophthalmus* fingerlings reached 1 billion (Table 3).

Today there are a myriad of small-scale hatcheries and nurseries (<1 ha in area) supplying Pangasiid seed in Viet Nam and the price of larvae is down to as low as VND 2–3 each. Vietnamese hatcheries and nurseries produce more than sufficient for local demand, with excess river catfish larvae and fingerlings being exported to Cambodia (Edwards, Tuan and Allen, 2004). However Government Decree 15/2006/QD-BTS will prohibit the export of live Pangasiid larvae and fingerlings from September 2007 onwards.

In stark contrast, Cambodian hatcheries only produced a total of 883 840 river catfish fingerlings in 2004 (So and Haing, 2006).

The first “basa” (*Pangasius bocourti*) hatchery in the Mekong Delta of Viet Nam began operation in 1996. Ten hatcheries (2 in An Giang; 2 in Tien Giang and 6 in Dong Thap provinces) produced an estimated 15–20 million *Pangasius bocourti* larvae in 2006, selling at VND 100 (approximately US\$0.006) each. *Pangasius bocourti* broodstock, which are held in cages, typically at stocking densities of 1.5–3 kg/m³, mature between February and June. *Pangasius bocourti* larvae are first fed on *Artemia* nauplii and later commercial pellets. Survival of *Pangasius bocourti* larvae nursed to fingerlings at 90 days is approximately 70 percent.

While the majority of *Pangasius bocourti* seed stocked in Vietnamese grow-out systems is from hatcheries, a small proportion is still wild-caught. Private and government hatcheries produced an estimated 15 billion river catfish and 3 billion *Pangasius bocourti* seed in 2004 (MOFI, 2005).

TABLE 3
River catfish larvae and fingerling production, 2004–2006

Years	Larvae (billion)	Fingerlings (billion)
2004	6	0.4
2005	8	0.7
2006	10	1

Source: Annual 2006 progress reports from the Provincial Extension Centres of An Giang, Dong Thap, Tien Giang, Vinh Long, and Can Tho provinces.

BOX 1

From wild seed fisher to hatchery owner**Hong My Hatchery, Hong Ngu district, Dong Thap**

Mr My began catching and trading wild Pangasiid seed (*Pangasianodon hypophthalmus*, *Pangasius bocourti* and *Pangasius krempfi*) 38 years ago. Following training on spawning from the provincial Department of Agriculture and Rural Development (DARD) in the 1990s, Mr My established his Pangasiid hatchery in Hong Ngu district, Dong Thap province, close to the border with Cambodia.

Today the hatchery holds 25 tonnes of “tra” (*Pangasianodon hypophthalmus*) of about 6 kg each, 6.5 tonnes of “basa” (*Pangasius bocourti*) of about 8 kg each and 1.5 tonnes of *Pangasius conchophilus* of about 1.8 kg each, all of which were obtained from wild stocks. Most of the broodstock are held in floating cages on the nearby river. The broodstock are used for 5–6 years before being replaced.

Mr My has a total of 6 ha of ponds, 3.5 ha of which he owns and the remainder are leased. Hong My hatchery sells 90 percent of its production as 1-day old larvae, while 10 percent is sold as fingerlings after 45 days of pond nursing. The hatchery is run by 5 family members and 15 hired labourers. The hatchery’s main operating costs are feed for broodstock and spawning chemicals. Its main constraints were reported to be disease occurrence and the low fecundity of “basa” (*Pangasius bocourti*). Hong My hatchery sells mainly to Vietnamese nursery farmers and also to Cambodian wholesalers.

Culture systems for “tra” (*Pangasianodon hypophthalmus*) and “basa” (*Pangasius bocourti*) catfish in Viet Nam

River catfish is the major freshwater finfish produced in the Mekong Delta region of Viet Nam (Phillips, 2002) because it is hardier, grows faster, is less expensive to produce and has a fecundity up to ten times higher than *Pangasius bocourti* (Edwards, Tuan and Allen, 2004). In addition river catfish also has a higher dress out weight than *Pangasius bocourti*, with 3.1 and 3.7–3.8 kg fish, respectively, required to produce 1 kilogram of fillet (Edwards, Tuan and Allen, 2004). While tra is the major exported freshwater finfish from Viet Nam, *Pangasius bocourti* is still preferred for local consumption and sells for one third more than river catfish.

Pangasius bocourti are cultured almost exclusively in cages on tributaries of the Mekong River. From 1995 to 1999 there were approximately 3 000 *Pangasius bocourti* cages in the Mekong Delta of Viet Nam, producing 30 000 tonnes annually, most of which was destined for the domestic market (Nguyen Tuan, 2000). With increasing focus by producers on river catfish for export, there has been a significant recent decline in *Pangasius bocourti* production, with 800 cages producing an estimated 12 000 tonnes in 2006.

In Viet Nam, river catfish (*Pangasianodon hypophthalmus*) are cultured in monoculture in cages and net pens along the edges of rivers, intensively in ponds and in polyculture systems in small-scale ponds (Hung *et al.*, 2003). An Giang and Dong Thap provinces have the greatest number of Pangasiid cages. Cage sizes in the Mekong Delta range from 50 to 1 600 m³, with larger cages commonly including living quarters on top and the submerged cage portion below (Phillips, 2002). Intensive pond culture of river catfish (*Pangasianodon hypophthalmus*) is concentrated in Can Tho, An Giang, Dong Thap, and Vinh Long provinces. Despite the higher risks (caused by high stocking densities and poor water flow) of characteristics unfavourable to export markets (e.g. yellow flesh), 50 percent of total Pangasiid culture is from ponds (Cacot, 2004). Small-scale pond culture of river catfish including in VAC systems (Vietnamese acronym for garden, pond, and livestock quarters) is also found throughout the Mekong Delta

(Edwards, Tuan and Allen, 2004). Recently river catfish and *Pangasius bocourti* have also been 'exported' to the northern and central regions of Viet Nam, and pilot culture has been conducted (Khanh 2004, cited in Hao, Hung and Trong, 2005). However to date, the majority of Pangasiid culture in Viet Nam is from the Mekong Delta.

River catfish can tolerate dissolved oxygen as low as 0.05–0.10 mg l⁻¹ (Browman and Kramer, 1985, cited by Cacot, 1999; Khanh, 1996), highly polluted water (chemical oxygen demand = 25), and being obligate air breathers, can be stocked at densities as high as 120 fish m⁻². River catfish reach 1–1.5 kg after 8 months of culture and being omnivorous adapt to different kinds of feed (Khanh, 1996). The feed conversion ratio of river catfish is typically 1.9–2.0 on commercial pellets.

Ponds are usually stocked at 60–80 fish m⁻², though some grow-out farmers may stock as high as 120 fish m⁻². Grow-out cages are typically stocked at 100–150 fish m⁻³. Yields reach 300–400 and exceptionally 500 tonnes ha⁻¹ crop⁻¹ in ponds, and 100–120 kilograms m⁻³ crop⁻¹ in cages. Yields as high as 500 tonnes ha⁻¹ crop⁻¹ have been reported from pen systems. Grow-out producers, have traditionally used home-made feed, but are increasingly moving to commercial pelleted feeds, which today supply an estimated 80 percent of feed inputs. Producers are aerating ponds and regularly exchanging pond water to reduce muddy off flavours and to produce whiter fleshed fish.

With increased culture area and intensity of Pangasiid production disease outbreaks like Bacillary Necrosis of *Pangasius* (BNP) are becoming more frequent. Outbreaks typically occur at the start of the rainy season (April–May) and the end of the flood season (October–November) (Crumlish and Dung, 2006). Although banned by the Ministry of Agriculture and Rural Development (MARD), many producers still treat diseases with antibiotics, plus disinfection agents. This has resulted in rejection of export shipments in Japan, the European Union and the United States of America. This is a priority issue for the government and the industry.

Production costs for pond and cage reared river catfish are relatively stable at approximately VND 7 000 kg⁻¹ (US\$0.43) and VND 9 000 kg⁻¹ (US\$0.56), respectively. River catfish and *Pangasius bocourti* products are exported to Europe (approximately 60 percent), Asian countries, Mexico, Australia (30 percent), the United States of America (<10 percent), and the Middle East. New markets like Russia are emerging.

In 2004 Pangasiid production reached 300 000 tonnes (MOFI, 2004). In 2005, a pond culture area of 4 912 hectares and 340 800 m³ of cages produced 416 908 tonnes of Pangasiid catfishes, with a total value of US\$2 393 million. Of this, pond culture of river catfish, cage culture of river catfish and cage culture of *Pangasius bocourti* were 89 percent, 10.5 percent and 0.5 percent respectively. Mean productivity of river catfish in ponds in 2005 was 75.6 tonnes hectare⁻¹ year⁻¹, while mean productivity of river catfish and *Pangasius bocourti* in cages was 140 and 67 kilogram m⁻³ year⁻¹, respectively (Southern Sub-Institute for Fisheries Planning, 2006). Estimated production of Pangasiid catfishes in 2006 was 842 000 metric tonnes, comprising 830 000 and 12 000 tonnes of river catfish and *Pangasius bocourti*, respectively. Viet Nam exported 286 600 tonnes of Pangasiid catfishes, valued at US\$736 million in 2006 (Source: Viet Nam General Department of Customs). Viet Nam's 2010 target production of river catfish and *Pangasius bocourti* is 1 million tonnes, with exports valued at US\$800 million¹ (Hao, Hung and Trong, 2005).

Culture systems for snakehead

Wild-seed based snakehead culture has been and still is practiced throughout the lower Mekong Basin, but is particularly important in Cambodia and Viet Nam.

Until the early 1990s, an estimated 15–20 million wild snakehead seed weighing 0.3–0.5 g were collected annually between March and May, using lift scoop nets in the Mekong Delta area of Viet Nam. From 1999 onwards hatchery produced snakehead

¹ Viet Nam surpassed 1 million tonnes of Pangasiid production in 2007.

met Viet Nam's demand for seed for stocking in grow-out systems. Today there are over 200 snakehead hatcheries in Viet Nam, with most located in Hong Ngu and Tam Nong districts of Dong Thap province. Broodstock are fed predominantly trash fish, and are held in small ponds, typically 200–500 m² in area. When broodstock reach maturity, farmers make net spawning enclosures in which the snakehead naturally lay and fertilize their eggs. Presently hatcheries in the Mekong Delta area of Viet Nam produce about 20 million snakehead larvae annually.

Larvae are typically nursed in a blue nylon hapa measuring 3 x 4 x 1.5 m, holding 500 larvae, and fed on trash fish and/or fishmeal and fine rice bran, with 20–30 percent survival. Annual production of snakehead fingerlings, from hatcheries and wild collection, is estimated to be 15–18 million.

In the Mekong delta in Viet Nam, giant snakehead (*Channa micropeltes*) are cultured in cages together with Pangasiid species. It is estimated that they contribute 5 percent of the total output from cages (Trong, Hao and Griffiths, 2002). The Research Institute for Aquaculture No. 2 (RIA 2), in the south of Viet Nam has been spawning giant snakehead at Cai Be in Tien Giang province for several years and their staff have been disseminating spawning, nursing and grow-out technologies throughout the country (Khanh, personal communication). However since monoculture of snakehead is dependent on locally available cheap trash fish, which is in short supply, it is unlikely that giant snakehead culture will be anything other than a small-scale activity throughout Viet Nam for the foreseeable future.

In 1998, 954 farmers cultured snakehead in ponds and cages in Dong Thap province. Stocking at 25–50 fingerlings m⁻², feeding low value freshwater trash fish, yields were 70–120 tonnes hectare⁻¹ year⁻¹ and total production was 4 641 tonnes. With the easy availability of hatchery produced snakehead seed, snakehead culture has expanded rapidly. Today stocking densities are typically 30–40 fish m⁻², and yields 100–150 tonnes hectare⁻¹ year⁻¹ of market sized, 500–700 gram fish.

Cage culture of snakehead is popular in An Giang province, where yields range from 42.5–116 kg/m³. In 2003, An Giang province produced 5 294 tonnes of giant snakehead (*Channa micropeltes*).

In 2006 total production of snakehead (*Channa micropeltes* and *Channa striata*) in Viet Nam was an estimated 25 000–32 000 tonnes (Phuong, personal communication).

In Cambodia, cage culture of snakehead (*Channa micropeltes* and *Channa striata*) has been practiced for over a century (Chevey and Le Poulain, 1940), but recently increased dramatically because they are high-value fish that can be marketed alive. Furthermore, they can be fed low value freshwater fish that are seasonally abundant in the country, thereby providing an efficient way of attenuating the seasonal peak fish harvest (Khay and Hortle, 2005). Cambodian snakehead culture (both cage and pen culture) is thus in a transition between capture and culture fisheries. The following examples illustrate this transition (Phillips, 2002):

- farmers who use the cages solely for transporting captured fish;
- farmers who hold and fatten fish for a few months, subsequently marketing them when price and demand are higher than at the time of capture; and
- farmers who stock wild-captured juveniles into cages and/or pens for feeding and grow-out to market size.

In 2004, there were 4 492 cages in Cambodia on the Tonle Sap Great Lake, and the Tonle Sap, the Mekong and Bassac Rivers (So and Haing, 2006), all of which at the time were entirely dependant on wild fish as seed, and feed (So *et al.*, 2005). An estimated 20 million wild seed were collected for cage culture in 2004 (So *et al.*, 2005), including 15.4 million giant snakehead seed, 1.1 million river catfish, 0.94 million *Pangasius conchophilus* and 0.62 million *Pangasius bocourti*. So *et al.* (2005) also estimate that 6.6 million wild river catfish fingerlings were stocked in ponds in Cambodia in 2004.

While Cambodia exported billions of river catfish fingerlings and tens of millions of *Pangasius bocourti* fingerlings in the 1980s, the trend reversed with the development of Pangasiid hatcheries in the Mekong Delta region of Viet Nam, with Cambodia importing 60 million fish fingerlings for cage and pond aquaculture in 2004, including 1.5 million river catfish. Viet Nam and thereafter Thailand became the major suppliers of seed to Cambodia.

While total hatchery production of fish seed in Cambodia expanded 33 fold from 560 000 in 1987 to 18.5 million in 2004 (So and Haing, 2006), Cambodian hatcheries supplied only 18 percent of the country's total aquaculture seed requirement in 2004.

Cage culture of snakehead was banned in Cambodia in 2005, because of its reliance on small wild fish as feed. This resulted in a partial shift to cage culture of hybrid catfish (*Clarias gariepinus* x *Clarias batrachus*) in Cambodia.

In Lao People's Democratic Republic, cage culture of snakehead based on wild-captured seed is commonly practiced in the Nam Ngum Reservoir. Seed appear to be a limiting factor as prices have been increasing (Hambrey, 2002). There may therefore be an opportunity for Viet Nam to export giant snakehead seed to Lao People's Democratic Republic.

FISH FEED

Since capture-based aquaculture was traditionally developed to even out the surplus from capture fisheries during the monsoon season, locally captured, low value fish constituted the basis for aquaculture feed, sometimes mixed with other on-farm products including rice bran.

The large yields of "trei riel" (*Cirrhinus siamensis*) and other low value species, constitute the basic feed for culture of both Pangasiid catfishes and snakeheads in Cambodia (Ngor, Aun and Hortle, 2005).

In the Nam Ngum Reservoir in Lao People's Democratic Republic, the locally available small freshwater clupeid "Pa Keo" (*Clupeichthys aesarnensis*) is the main feed ingredient for the cage culture of snakehead (Hambrey, 2002).

Until recently, 95–97 percent of Vietnamese Pangasiid cage culture systems used home-made feeds (Phu and Hein, 2003). Food safety concerns, fluctuating quality, rising trash fish costs and the establishment and expansion of the fish food production industry in Viet Nam have encouraged farmers to increasingly use commercial pelleted feeds for monoculture grow-out of Pangasiid catfishes in cages and ponds. At present the division between home-made and manufactured feed is approximately 20:80. Pangasiid catfishes are also produced in small-scale integrated grow-out systems in polyculture with other species and fed with small marine and/or freshwater fish species which are either bycatch or targeted low-value species, as a supplementary feed (Edwards, Tuan and Allen, 2004).

Factoring in levels of trash fish in home-made diets and fishmeal content in pelleted feeds for Pangasiid catfishes, moisture content and FCR, Edwards, Tuan and Allen (2004) estimated that a minimum of 64 800 to a maximum of 180 000 tonnes of trash fish were used to produce the 180 000 tonnes of Pangasiid catfishes that Viet Nam produced in 2002.

ENVIRONMENTAL IMPACTS OF CAPTURE-BASED AQUACULTURE

Impact of juvenile and fry fisheries

Pangasiid catfishes

The capture of Pangasiid catfish juveniles has largely been replaced by hatchery-reared fry for the main catfish industry in the Mekong Delta of Viet Nam. However, operations in Cambodia, Lao People's Democratic Republic and, to a lesser extent Thailand, still use wild-captured juveniles as seeds for cage and pond culture.

The collection of Pangasiid larvae from the Mekong delta has generally been perceived as unsustainable and detrimental to the target species as well as to the many other species caught as bycatch in the fisheries. For instance, Trong, Hao and Griffiths (2002) cited information from Donh Thap Province that the capture of Pangasiid larvae had declined tenfold during the past decade, “due to over-fishing”.

The bycatch from the fishery is significant. Phuong, 1998 (cited in Trong, Hao and Griffiths, 2002) estimated the bycatch at between 5 to 10 times (by weight) the catch of the targeted Pangasiid larvae. Trong, Hao and Griffiths (2002) concluded that the fishery for catfish fry was “highly destructive” for both the catfish populations themselves as well as for other species caught as bycatch.

Although it is easy to draw the conclusion that the catch and bycatch levels are and were detrimental, no data exist to support this claim. In general, most fish species of the Mekong are adapted to high larvae and juvenile mortalities as a result of living in the versatile, but productive floodplain habitats.

The Mekong River Commission (MRC) has facilitated several studies over the past 6–7 years on larvae and juvenile drift in the lower Mekong in both Viet Nam and Cambodia. Data from these surveys do not indicate any reductions in numbers of larvae in recent years.

Genetic studies of *Pangasianodon hypophthalmus* do not suggest any recent declines in genetic diversity and/or population sizes (So, Volckaert and Srun, 2006). They attribute the high genetic diversity of *Pangasianodon hypophthalmus* to the large and productive feeding habitats associated with the Mekong floodplains.

Although existing information is inconclusive, fisheries catch data (e.g. Tonle Sap Dai fisheries, described in Lieng, Yim and Van Zalinge, 1995), larvae sampling and recent genetic studies suggest that *Pangasianodon hypophthalmus* and *Pangasius bocourti* have not suffered recent population size declines. Any negative impacts of juvenile fishing seem to be negligible and the annual recruitment appears to have been able to absorb the fishing pressures on all life stages of the species.

However, there may be some impacts of these fisheries at the sub-species population level. Although such impacts are currently little understood, genetic studies on the larval drift of *Pangasianodon hypophthalmus* have revealed that up to five sub-populations exist, which are temporally separated in the drift and therefore probably represent distinct spawning populations of the species. Two of those populations were not found downstream of Phnom Penh and in the Mekong delta, where three relatively common populations were identified. Interestingly, studies on the larval drift in the Mekong delta in Viet Nam also identified three temporally separated peaks of *Pangasianodon hypophthalmus* larvae, corresponding to these three genetically distinct populations (Nguyen *et al.*, 2006).

The two other populations appear to be rare and could potentially be impacted negatively by juvenile fisheries at certain times and/or places. The reason why two out of five populations appear to be comparatively rare is not currently understood. Further studies, combining ecological and genetic methods, will be needed to shed light on this issue and possibly suggest management implications (So *et al.*, 2006b).

Population genetics of migrating Pangasiid catfishes in the Mekong is extremely complex and genetic research is only just beginning to reveal some of these subtle characteristics that nevertheless may have important management implications. For instance, one interesting observation coming out of recent genetic population studies is that one of the ecological drivers of the high number of sympatric intra-species populations may be the disproportionate availability of productive nursery and feeding habitats compared to spawning habitats (So, Maes and Volckaert, 2006). Different populations use the same spawning sites, but at different times of the spawning season, and all the off-spring are subsequently mixed and distributed throughout the vast nursery areas on the floodplains. As a consequence, the management priority for sustaining these

species and populations should be the conservation of their spawning sites.

Potential genetic impact of hatchery-reared fry on wild populations is another issue related to genetics that is little understood and not documented for the Pangasiid catfishes. Such impacts may occur if hatchery-reared fish escape to the natural environment and interbreed with wild populations. If broodstock are taken from the local environment, as is generally the case for the catfish industry in the Mekong delta in Viet Nam, such impacts would be minimal.

However, if broodstock are transferred to other areas, particularly if those are in different river basins, such impacts could be significant. For instance, broodstock used in the aquaculture industry in the upper Mekong in Thailand probably originate from the Chao Phraya River basin and are genetically different from the wild populations of the Mekong basin. Chao Phraya broodstock have also been imported to Cambodia for use in aquaculture. This practice was subsequently stopped, because of concern that fish might escape and breed with the wild populations (So and Haing, 2006).

In Viet Nam, broodstock from wild populations of *Pangasianodon hypophthalmus* are taken in on a regular basis to maintain genetic diversity of aquaculture broodstock – a practice that effectively ensures that the genetic integrity of the wild populations will not be compromised by hatchery-reared material.

Ish and Doctor (2005) ranked the risk to wild Pangasiid stocks from escaping cultured Pangasiid catfishes as “low” because most cage structures are floating and sited in relatively sheltered areas. In addition, because most Pangasiid broodstock are from wild populations, and to date there has been minimal selection and improved breeding programme work conducted the genetic diversity and make-up of hatchery and wild Pangasiid fish populations are essentially the same. Hybridization of *Pangasius bocourti* and *Pangasianodon hypophthalmus*, while possible, has been banned by MOFI and the ban is being enforced.

Snakeheads

As with the Pangasiid catfishes, there is no data to suggest that juvenile snakehead fisheries have negative impacts on the species. Again, the large annual recruitments appear to be able to counteract any potential negative impacts.

Channa striata is one of the most common species of the lower Mekong basin and one of the most frequently encountered fish at markets throughout the basin. It is well adapted to living in rice-field habitats and therefore, may in fact have benefited from anthropogenic impacts, including the conversion of natural habitats to paddy fields.

Due to its conspicuous spawning behaviour including parental care of the larvae, adults and juveniles are easily captured by fishers. Parents guarding snakehead seed are easily identified in shallow waters and can simply be scooped up by net together with the entire larvae shoal. Therefore, the potential impact on populations of other species appears to be minimal, although no data exist to confirm this.

Aquaculture feed

Since the culture of both catfishes and snakeheads is based on the use of low value and/or trash fish, concerns have been raised about the environmental impact of the practice. For instance, earlier estimates suggested that up to 300 000 tonnes of trash fish are used as fish feed for the river catfish and *Pangasius bocourti* industry in Viet Nam annually (Sverdrup-Jensen, 2002). This figure must now be significantly higher due to the recent increase in Pangasiid catfish production from this area.

When the production of cultured fish was based on the traditional capture-based system (i.e. the use of a seasonally abundant, low value fish resource to produce a high-value product that could be marketed outside the peak season) the practice could probably be carried out in a sustainable manner. However, as the Pangasiid industry, in particular, has developed into a large export industry, the demand for trash fish has

exceeded local supply. As a result, marine trash fish are now also used as a feed for the culture of Pangasiid catfishes and snakeheads. This raises environmental concerns, not only locally, but for the marine environment and fisheries that supply the trash fish.

The use of wild-caught trash fish for aquaculture feed is also practiced for other capture-based aquaculture activities in the Mekong basin. Large quantities of the indigenous cyprinids *Cirrhinus siamensis* and *Cirrhinus lobatus* are used throughout the basin, but particularly in Cambodia. An unknown (but significant) amount of the Cambodian catch of *Cirrhinus* sp. is transported across the border to Viet Nam to satisfy the need of the expanding Pangasiid catfish culture industry.

Feed for snakehead culture in Lao People's Democratic Republic and Thailand is mainly based on the capture of the small freshwater clupeid *Clupeichthys aersarnensis*, from reservoirs (e.g. Nam Ngum Reservoir in Lao People's Democratic Republic). In Thailand, slaughter-house waste, particularly from chicken processing, is also used as a feed supplement for snakehead culture (Simon Funge-Smith, personal communication).

The use of wild fisheries resources for feed is the main environmental sustainability challenge that currently faces the Pangasiid catfish industry in the Mekong Delta of Viet Nam. Research efforts aiming at reducing the use of feeds based on trash fish are on-going.

OTHER ENVIRONMENTAL ISSUES

Disease

Crumlish *et al.* (2002) identified the bacteria *Edwardsiella ictaluri*, a disease native to North America and *Ictalurid* catfish, in farmed river catfish cultured in the Mekong River Delta. This was the first time this disease was recorded in Pangasiid catfishes. As yet it is not known whether the bacteria was indigenous but previously unknown, or if it was introduced from overseas. There are no data as yet to show that wild stocks have been affected by this disease. Additionally there is no evidence to suggest that wild Pangasiid stocks are suffering more disease as an impact of contact with cultured Pangasiid catfishes, particularly those in cages.

Effluent

Monoculture of Pangasiid catfishes in cages which are open net containers, and ponds which are drained into canals and rivers, impact on the natural water environment by increasing nutrient and suspended sediment loads and increasing Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). The high water temperatures in the Mekong Delta region of Viet Nam allow primary consumers to proliferate which rapidly break down ammonia, nitrates, and organic matter released in faecal wastes from Pangasiid cages and ponds. However despite this, anoxic conditions can occur in localised areas where there are more cages and ponds than the carrying capacity of the area can sustain.

Other issues

Diseases and water quality issues pose serious threats to the future of the industry. Export markets will in the future increasingly demand that products live up to both product quality standards as well as social and environmental sustainability standards. If Viet Nam's current level of export is to be maintained (and, according to official targets, even increased) standards will have to be developed and implemented for the industry. The Sustainable Aquaculture Group of Viet Nam is proposing to commence a study on the Pangasiid production carrying capacity of the Mekong Delta region of Viet Nam in 2008.

SOCIAL AND ECONOMIC IMPACTS

No studies exist on the social and economic impacts of the wild-capture fisheries for aquaculture seed in the lower Mekong basin. The development of the Pangasiid catfish industry in Viet Nam has had tremendous economic impacts both at national and local levels. The entire industry, including the research activities and subsequent hatchery development that has rendered the wild seed fisheries for Pangasiid catfish seed obsolete, was initially triggered by the traditional capture of Pangasiid catfish seed.

The capture of wild seed is generally carried out by relatively poor fishers in the Mekong basin and the captured juveniles provide much needed additional seasonal income. The banning of the fisheries may therefore have had significant local-level socio-economic impacts which were not assessed prior to the introduction of bans. In some cases, the bans resulted in fishing gear confiscation, causing additional economic loss to fishers.

As Box 1 shows, some Pangasiid catfish juvenile fishers were able to take advantage of the subsequent hatchery development and become seed producers after the capture seed fishery was banned.

There do not appear to be any data or information on the socio-economic importance of the juvenile fisheries for Pangasiid catfishes and snakehead in the Mekong basin, including the socio-economic impacts that bans on certain fisheries (such as the dai fisheries for Pangasiid larvae) have had on local fisher communities.

MANAGEMENT

Often the capture of juvenile fishes is seen as a wasteful practice. Conventional wisdom tells us that juveniles should be left to grow to their full potential before being harvested. This conventional wisdom has also taken hold in the Mekong basin, where the capture of juvenile fishes for use in either culture or consumption has generally been banned.

In Cambodia, the bag net (dai) fisheries targeting Pangasiid larvae were banned in 1994. However, in spite of the ban, the number of bag net units in operation increased to 948 in 1998, up from 650 units in 1981 (Van Zalinge *et al.*, 2002). Since then however, enforcement has been strengthened. The “New Fisheries Law” calls for the protection of aquatic biodiversity and the environment (So and Haing, 2006).

In Viet Nam, the “New Fisheries Law” came into force in 2003. This is a legislative framework within which specific directives will be developed to accommodate the legal aspects of specific fisheries issues, such as capture fisheries management, aquaculture and habitat/species conservation.

In relation to the capture of wild seed for aquaculture, the New Fisheries Law states that the exploitation of fish smaller than regulated size is prohibited, except for permitted aquaculture purposes.

The provincial authorities in Viet Nam have some legislative powers for specific management regulations of provincial level fisheries, including juvenile fisheries. In both An Giang and Dong Thap provinces, for instance, the use of dais to capture *Pangasianodon hypophthalmus* larvae was banned in 2000. The timing of this ban coincides well with the emergence of increased hatchery seed production that was subsequently able to meet the Pangasiid seed demand of the area.

Regulations for snakehead juvenile fisheries, include some size restrictions, e.g. in An Giang Province the capture of snakeheads below 10 cm in length is illegal. From 1 May to 1 June each year, fishing for juvenile snakeheads is completely banned to reduce fishing pressure during the peak spawning season of snakeheads (Sjorslev, 2001). However, enforcement of these regulations appears to be extremely weak.

Most existing legislation related to the capture of juveniles and their use in aquaculture, is generally based on weak and unreliable data.

With the massive recruitment occurring within the Mekong ecosystem, for at least three of the four species covered in this paper, and with the extreme seasonality of the fisheries, the capture of juveniles may actually be a sustainable resource exploitation approach. The key management issue for the sustainability of the capture-based aquaculture practice is whether the use of trash fish-based feeds is sustainable, and if not, whether these feed inputs can be replaced by other protein sources.

In the extremely complex and multi-species setting of the Mekong basin fisheries, it is important that all management issues are seen within the larger, ecosystem context. Experiences from past decades suggest that if essential habitats for the targeted species are protected and maintained (in terms of quality as well as quantity), juvenile fisheries can continue to be conducted in a sustainable manner.

CONCLUSIONS

- Aquaculture traditionally developed in the lower Mekong basin as an integrated element of capture fisheries to transfer a low value, seasonal surplus into high-value fishes (such as Pangasiid catfishes and snakeheads) that could be marketed all year round.
- Wild seed is used in cage and pond culture (Pangasiid catfishes) and cage and pen culture (snakehead) throughout the basin, particularly in Cambodia and Viet Nam.
- Traditionally, these culture systems relied on wild-caught, low-value “trash fish” from the Mekong (e.g. the small cyprinid genus *Cirrhinus*) as feed. This is still the case in most places. Today marine trash fish are also being utilized as a feed input to accommodate the increasing demand in the Mekong Delta of Viet Nam. Trash fish, however, is increasingly being replaced by commercial pelleted feeds, particularly in Viet Nam.
- For Pangasiid catfishes, traditional capture-based aquaculture systems triggered the development of hatchery technology which today meets the demand for seed within Viet Nam and Thailand, with surplus seed exported to Cambodia and Lao People’s Democratic Republic.
- Snakehead culture continues as a capture-based aquaculture system in most parts of the basin, except in Thailand. The large recruitment from natural ecosystems and their relatively easy capture means that large-scale hatchery production of snakehead seed (particularly the giant snakehead, *Channa micropeltes*) is financially unattractive.
- Current data and information suggests no significant negative impacts of juvenile fisheries on wild populations of Pangasiid catfishes and snakeheads. Both species groups have maintained healthy and extremely productive wild populations in spite of juvenile fishing pressure.
- For the two main Pangasiid species, recent genetic studies indicate that the bottleneck for sustainable management of both species is the protection of their spawning habitats.
- When wild capture of aquaculture seed is increasingly replaced by hatchery-reared seed (as has happened with Pangasiid aquaculture in the Mekong delta of Viet Nam), it is important to introduce sound genetic management practices. These include using broodstock of local origin and/or periodically replacing broodstock with newly captured wild broodstock from local sources.
- The use of low-value/trash fish from within the Mekong basin as well as from marine sources poses the biggest challenge to the industry in terms of ecological and environmental sustainability.
- The socio-economic importance of past and present juvenile fisheries in the Mekong basin, and their subsequent banning in some areas, has not been adequately assessed.

- Capture-based aquaculture, including the practices of capturing juveniles and using wild-captured resources for feed, should be assessed and managed within a larger-scale ecosystem approach.

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Capture-based aquaculture of *Clarias* catfish: case study of the Santchou fishers in western Cameroon

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SUMMARY

Aquaculture is an expanding activity in Cameroon. The limited availability of high quality fingerlings and feeds has been identified as one of the factors constraining its further development. Following the failure of government owned stations to meet this demand, effort is being put into seed production in private hatcheries. However, wild-caught seed remains important, especially *Clarias* species seed caught in the Nkam River basin in the western and littoral provinces of Cameroon.

This report presents a review of *Clarias jaensis* and *Clarias gariepinus* in Cameroonian capture-based aquaculture, with a focus on the market chain and socio-economic and environmental challenges related to the collection and use of juveniles of these species from the wild. The data and information presented here derive from research undertaken in participation with the fishers of the Nkam Valley in Western Cameroon under the Construction de l'Innovation Piscicole (CIP) project (Annex 1). Specific exchanges with key stakeholders involved in the fishery were conducted from January to March 2007.

Clarias spp. are silurid fish with interesting features for aquaculture. *Clarias gariepinus* appears as the most promising on account of its faster growth. However, it does not reproduce spontaneously in captivity, and hatchery operators need to induce spawning through injection of gonadotropic hormones. In addition, high mortality is observed in the early stages of the life cycle and relatively intense management is required to achieve high survival rates of fingerling in ponds, particularly with regards to reducing predation and cannibalism and ensuring the availability of adequate live feed needed during the larval phase. These constraints are currently being addressed through participatory research with Cameroonian fish farmers.

In the Nkam Valley, annual flooding provides millions of catfish juveniles that are collected by fishers and fish farmers for direct consumption or restocking of flooded ponds extensively used by farmers in traditional aquaculture. The collection of juveniles, along with the harvesting of flood ponds, takes place from November to March when the dry season results in the flooded rivers receding from farmed lowlands.

As aquaculture expands in the region, farmers from the highlands are now also seeking catfish juveniles, and a new economic activity has emerged to supply *Clarias gariepinus* fingerlings of homogenous sizes to buyers. This requires new inputs from the fishers including: sorting of species and sizes, handling the fish with greater care, stocking and nursing them in controlled rearing structures and better marketing. Of the many aspects affecting the survival of wild caught catfish in ponds, the two following were identified as critical: how long the fish remain in the mud during pond draining, and the water exchange rate during stocking and transportation.

In 2006, about 10 tonnes of catfish were harvested from flood ponds. Over 300 000 *Clarias jaensis* were collected and distributed for aquaculture, along with almost 50 000 *Clarias gariepinus*. In addition to fish consumed in the household (31 percent) or given to relatives (34 percent), estimated cash revenue of US\$20 000 were received by the 100 fishing households under investigation.

Compared to farmers in areas around the urban centre of Yaoundé, farmers of the Nkam Valley appear to be consuming 10 times more fish. Most fishers were married (75 percent), with an average of 7 persons in the household. The relatively high literacy rate (>70 percent beyond primary school) provides the potential for training in sustainable management of the resource.

To improve the value of the catfish fingerling harvest to both collectors and consumers, it is recommended that fishers are: 1) trained in proper fish handling, and 2) ensure purchase and use of appropriate farming and handling equipment through some form of revolving credit plan. The positive influence of traditional beliefs of the Mbô people on the sustainable management of the fishery, both wild juveniles and broodstock for aquaculture purposes, is also discussed in the report.

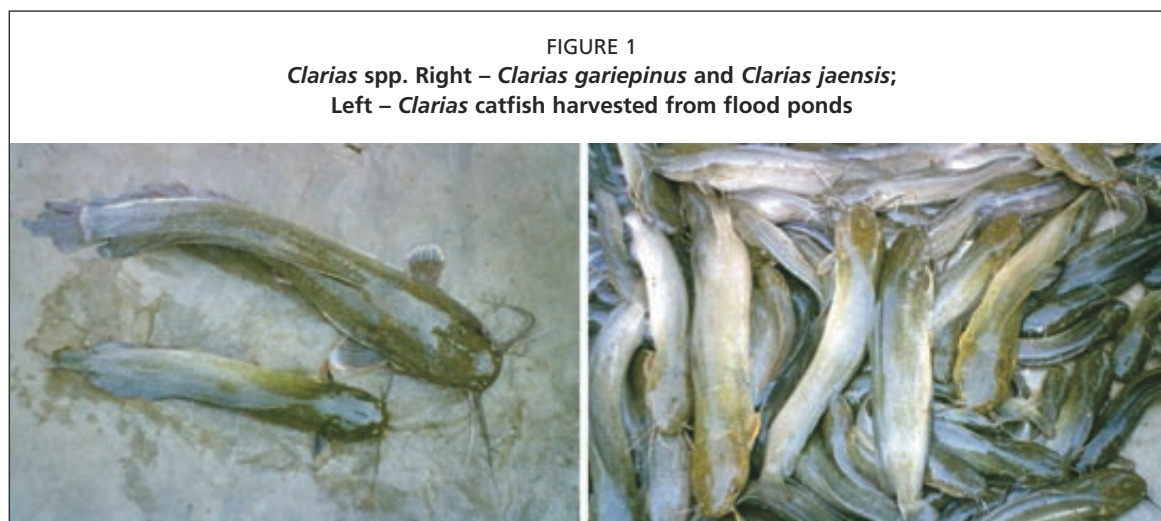
INTRODUCTION

Catfishes of the genus *Clarias* (Siluroidei, Claridae) are widespread in tropical Africa and Asia (Sudarto, 2007). *Clarias gariepinus* is by far the most cultivated. However, as they do not normally reproduce spontaneously in ponds, *Clarias* catfish culture is constrained by seed availability. Induced breeding has been developed, but production systems and hatchery management techniques that make catfish seed of good quality readily available to all farmers are yet to be established in most African countries (Pouomogne, Nana and Pouomegne, 1998; Brummett, 2007). In these conditions, seed from the wild remains an important opportunity, when available.

The use of catfish seed from the wild for typical pond aquaculture is not documented in Africa. However, a number of reports have described the traditional practice of enhancing the natural entry of wild fish into flood ponds, such as the “fingerponds” in Lake Victoria wetlands (Unesco-IEH, 2005), and “whedoes” used in Benin and Togo (King, 1993). These traditional aquaculture facilities can be owned by individuals or communities. Due to their location in wetlands, they are often not able to be drained and are typically harvested by intensive capture fishing as water recedes at the end of the dry season, and are sometimes referred to as “amplified fisheries” rather than aquaculture (Mikolasek, Massou and Allagdaba, 2000; Dorey *et al.*, 2002).

This paper focuses on African catfishes, specifically the use of wild-caught *Clarias jaensis* and *Clarias gariepinus* for aquaculture in the western Cameroon highlands. Although aquaculture production based on this practice remains marginal in Cameroon, this case highlights the interplay between the protection of the environment, poverty alleviation from well-managed inland fisheries and the gains to the overall society when rights of minor native groups are respected.

The study is based on secondary sources of information and data derived from published papers and unpublished reports. The author is part of an action research team working with farmers in the study area since 2003 through numerous projects



sponsored by the Ministry of Research and Innovation in Cameroon (MINRESI) and the French international cooperation agency. For the specific needs of the present study, additional primary source data and information were also collected from the field through interaction with fishers (see details on CIP project in Annex 1).

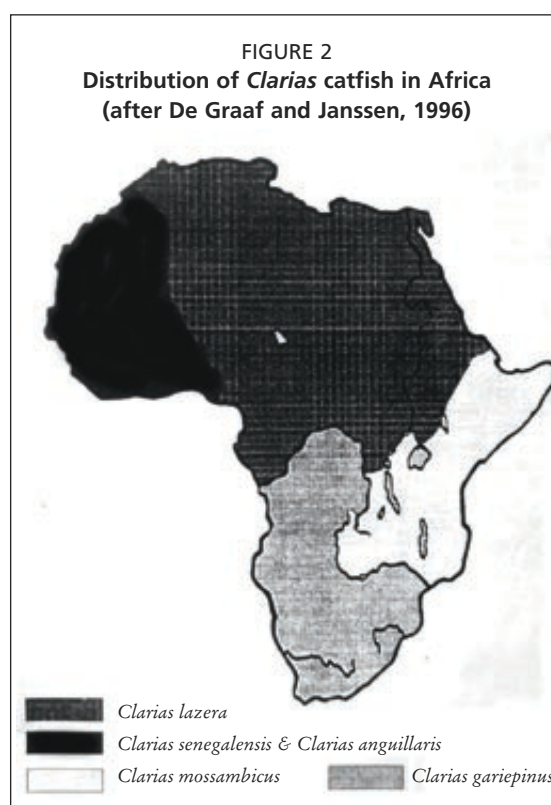
DESCRIPTION OF *CLARIAS* SPP. AND ITS USE IN AQUACULTURE

Taxonomy and life cycle

There are 58 species in the genus *Clarias* (Siluroidei, Clariidae) recognized in FishBase (2007), all living in freshwater, but able to tolerate salinities up to 2.2 ppt (Clay, 1977). Two species are the focus in the present study, namely *Clarias gariepinus*, and *Clarias jaensis* (Figure 1). Both are catfishes from the Clariidae family, which distinguish themselves from the other genera of the family by the presence of a single, long dorsal fin that extend nearly to the caudal fin base, among other distinguishing features. The naked mucus-covered body is elongate, eel-like, the head is flattened, and eyes are small. *Clarias gariepinus* grows bigger (maximum size recorded 1.7 m total length, in comparison to 0.5 m for *Clarias jaensis*) (Pauguy, Lévêque and Teugels, 2003). The skin of *Clarias gariepinus* is thicker than that of *Clarias jaensis*. The cephalic bones of the latter are almost visible throughout the relatively shorter and smoother under-surface of the head.

Clarias jaensis is the easier to handle of the two and shows a quieter behaviour in the rearing environment. *Clarias gariepinus* is usually dark spotted greyish coloured; *Clarias jaensis* is more dark yellowish. After cooking, *Clarias jaensis*' bones soften so that the whole fish can be consumed. According to the fishers in the Nkam Valley, *Clarias gariepinus* is the desirable and preferred aquaculture candidate, while *Clarias jaensis* is favoured in traditional dishes and for marriages and other customary celebrations.

Clarias gariepinus, generally considered to be the most important clariid species for aquaculture,



has almost pan-African distribution, ranging from the Nile to West Africa and from Algeria to South Africa. *Clarias jaensis*' distribution is less known. In Cameroon, this species is found in the Wouri and the Sanaga river basins, usually sympatric with the introduced *Clarias gariepinus*. The broad adaptive capabilities of *Clarias* species allowed their introduction to Europe, the Middle East and Asia (Figure 2).

These clariid species are found in lakes, streams, rivers, swamps and floodplains, many of which are subject to seasonal drying. The most common habitats of these species are floodplain swamps and pools where the catfish can survive during the dry seasons due to their accessory air breathing organs (De Graaf and Janssen, 1996).

Gonadal maturation in *Clarias gariepinus* is usually associated with the rainy season. In Cameroon, reproduction begins in late March-early April with the start of the rainy season. Heavy flooding in the Nkam Valley is observed by October–November, and fingerling collection takes place a month later when the water recedes back to the river bed. Flood ponds are harvested from January to March, with production varying from 200 to 800 kilogram/100 m² pond. The average individual fish weight is 167 grams.

Fishery exploitation of *Clarias* catfish

Total freshwater fish production of catfish from the genus *Clarias* is estimated at 75 000 tonnes and is second only to Tilapia among the freshwater fish species captured in Cameroon (Ngok, Njamen and Dongmo, 2005).

In the Sanaga and Wouri River basins, total capture fisheries production is estimated at 15 000 and 4 000 tonnes, respectively. From this, catfish can be reasonably estimated to contribute approximately one third of the catch, i.e. 6 000 tonnes. The total national production of *Clarias* catfish may be close to 20 000 tonnes.

The collection of wild *Clarias* fingerlings for aquaculture is less important than fishing for direct human consumption. In Cameroon the collection of catfish juveniles for aquaculture is specific to the Nkam River basin while it remains a marginal activity in other rivers where *Clarias* spp. are fished.

Wild *Clarias* fingerlings

The weight of fingerlings collected for aquaculture ranges between 20–120 grams. Table 1 shows the length-weight relationships for the most commonly marketed fingerlings in the Nkam Valley.

Clarias are relatively robust fish and tolerant of low dissolved oxygen water levels. *Clarias jaensis* demonstrates a quieter behaviour, and is thus easier to handle compared to *Clarias gariepinus*. Nevertheless, the holding and feeding of fingerlings is problematic in Cameroon. The most common error is stocking with different sizes in the same container. As larger fish cannibalize smaller individuals, survival rates of less than 10 percent are common and can occur in less than 5 days of stocking. Another problem is artificial feeding. Uneaten feed rapidly deteriorates water quality, causing high mortalities among smaller fish and swollen bellies in larger specimens.

TABLE 1
Length-weight relationship for marketed fingerlings collected from the wild in the Nkam Valley

<i>Clarias gariepinus</i>					
Total length (mm)	175	180	195	200	227
Weight (g)	30	35	42	57,5	118,5
<i>Clarias jaensis</i>					
Total length (mm)	160	165	214	223	243
Weight (g)	30	36,5	80,9	95	132,5

Source: Pouomogne and Mikolasek, 2007.

Tilapia-*Clarias* polyculture

Nile tilapia is the most commonly farmed fish in Cameroon. In mixed-sex culture, this species produces large numbers of unwanted juveniles. Overcrowding is controlled by using predator fish. *Clarias gariepinus* is the most commonly utilized species for this. Large fingerlings of 15 grams are stocked with Nile tilapia at a 1:1 ratio and reared for 9 to 11 months. Unfortunately, catfish fry production from existing hatcheries in Cameroon is poorly organized and managed, and unit prices may vary from US\$0.1 to 0.25. A recent economic analysis showed that at the current fish seed price of US\$0.2 per 5 gram fingerling most rural farmers are losing money, as farm profitability is possible only with a fingerling unit price of US\$0.1 or less (Brummett, 2005; Sulem *et al.*, 2007). When wild seed are available, prices of *Clarias gariepinus* fingerlings are generally lower than US\$0.1.

Clarias fingerling production and the benefits of wild-caught juveniles

African catfish reproduce in response to environmental stimuli such as a rise in water level and inundation of low-lying areas. These events do not occur in captivity and several techniques have been developed to induce artificial spawning on fish farms.

In Bamenda, located in the western highlands of Cameroon, ponds of about 300 m² are filled with ± 20 cm of water and stocked with 4 mature couple of *Clarias gariepinus* (250–450 g weight) for 2–4 days in April (i.e. early rainy season). Water level is then increased up to 60 cm (artificial flooding) by early afternoon and spawning usually occurs at night. The number of fingerlings harvested 4–6 weeks later per kilogram female brooder is <400 and average weight is 5 grams. This is a rather poor outcome.

In one hatchery at Foreke, 10 kilometres from Santchou, hormone treatment is employed to ensure large-scale production of catfish fingerlings. Hormones used include Deoxycorticosterone Acetate (DOCA), Human Chorionic Gonadotropin (HCG), Luteinizing Hormon Releasing Hormone Analogue (LHRH-A) or pituitary glands from a catfish brooder, common carp, Nile tilapia and even frogs following specific technical procedures (De Graaf and Janssen, 1996; Pouomogne, Nana and Pouomogne, 1998). These procedures include hormone preparation, injection and stripping of the eggs from females following a precise time interval. Protecting the pond from predators is a key parameter in the survival of the fingerlings. In a well-managed pond, over 20 000 fingerlings can be produced, with an average weight of 5 g per kilogram/female brooder. Although the procedures are being simplified, only a few farmers have been exposed to them. However, with the support of the WorldFish Center and the Institut de Recherche Agricole pour le Développement (IRAD), a larger number of farmers are being trained in these techniques (Nguenga and Pouomogne, 2006; Sulem *et al.*, 2007).

For fish farming to develop sustainably in Cameroon, catfish fingerlings need to be available at less than US\$0.1/unit compared to the current US\$0.15–0.25 price. The seasonal availability of natural fingerlings in the Nkam Valley is certainly an economically viable source of fingerlings; however such resource needs to be sustainably managed.

For the flood ponds in the Nkam Valley, pond preparation is performed just after harvesting in January–March at the end of the dry season, with the extraction of the bottom mud and rehabilitation of the fish shelters (Hem and Avit, 1994). Sunshine stimulates natural productivity before the start of the next rainy season in early April (Table 2). In normal years, flooding of the Nkam River and its tributaries occurs in July–October. Flood ponds are inundated at that time and fish recruit naturally to find the necessary food and shelter. Depending upon the severity of drying between rainy seasons, pond productivity may rise for 1 to 3 years before the pond is actually harvested.

TABLE 2
Preparation of flood ponds at Santchou, Nkam Valley

Periods	Activities	Events
April–July	None	Rainy season starts; Weedy grasses and shrubs start invading the sites (the main shrub being <i>Alchornea cordifolia</i> or “ben” in the local language)
August–October	None	Ponds are inundated
November–December	Site visits	End of rainfall and dry season starts; collection of catfish fingerlings by fishers
January	Pond visit and planning of harvests; supplemental fish feeding by some farmers	Water retreat starts in ponds
February–March	Pond draining; fish harvesting; pond rehabilitation	Traditional rituals, site clearing, harvests; pond repairs; building of shelters inside the ponds
April	End of a cycle	Rainfall comes back, with weedy grasses

Source: Translated from Mfossa, 2007.

The collection of catfish fingerlings from fishing grounds (as opposed to flood ponds) begins in early December with the start of water retreat. The majority of the fish caught are sold for non flood pond stocking in the highlands or for consumption; some fishers may however add fingerlings to their flood ponds periodically. In this case, farmers provide supplemental feeding with table scraps. Average pond size and depth in Santchou valley are 40 m² (475 ponds, range 2–240 m²) and 1.7 m (range 0.5 to 3 m), respectively. Stocking occurs via natural recruitment during the annual pond flooding. Most ponds are harvested after a one-year rearing cycle (52 percent) or after 2 years (45 percent). Exceptionally high productions is sometimes recorded at up to 860 kg per 100 m² flood pond per year.

DESCRIPTION OF THE FISHING ACTIVITY

Geographic overview of juvenile collection in the Nkam Valley

With the flooding of the Nkam and Menoua valleys numerous refuge sites for the young catfish are established in the nearby lowland farms (Figure 3).



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In addition to fishing for juvenile clariids, there is also a traditional practice of extensive fish farming of catfish in flooded ponds. The main villages concerned with the fishery for juveniles and the catfish aquaculture include Lelem, Ngang, Santchou and Fongwang. Ngang Island is particularly well known as a good fishing ground.

Fishing gear and materials used for the collection of *Clarias* juveniles

Fishing materials are generally artisanal and consist of 10 to 30 litre buckets, gasoline water pumps for draining water from the fishing grounds, hand nets, seine nets, cast

FIGURE 4
Fishing basket (right) and a two-wheel carrier used for transporting juvenile fish (left)



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nets and baskets used to catch the juveniles. Materials for transporting the catch from the fishing sites to the market includes 10–40 litre plastic or aluminium containers, canoes, bicycles, and wheelbarrows. (Figure 4).

Production statistics

Data on fishery production has not been regularly collected. Current estimates indicate values of 7.5 and 1.1 tonnes per year for *Clarias jaensis* and for *Clarias gariepinus*, respectively (Mfossa, 2007). Forty percent of the production consists of juvenile catfish averaging 10–40 grams in weight for potential use in aquaculture (approximately 0.3 million *Clarias jaensis* and 0.04 million *Clarias gariepinus*). National data indicate that the total freshwater aquaculture fish production in 2006 was 870 tonnes, of which 330 tonnes consisted of *Clarias gariepinus* (Pouomogne, 2007b).

Seasonality of fishing activities

Fishing begins in mid-November with the retreat of the water from the valley. The fishery usually continues until late March of the following year and stops with the arrival of the new rainy season. Professional fishers continue fishing throughout the year in other locations during the rainy season when heavy flooding precludes safe fish capture activities in the valley.

Fishing sociology – tribe, gender, division of labour

The Mbô, the indigenous people of the valley, are the main ethnic group involved in the fishery for juveniles and have ancestral rights to most fishing grounds. In Lelem village, the people of the Bamileke tribe own some farm areas in the lowlands where fishing for catfish juveniles can be undertaken.

Men, women and children all actively participate in the fishing, care of the flood ponds and harvesting activities. Men are particularly engaged in pond construction, management and harvesting, as such activities demand hard labour. Women are more involved in activities such as the distribution of the fish to the various destinations and smoking of the fish. Selling of the fish is mostly a male responsibility (Table 3).

Handling and holding

The distance from the fishing ground to the fisher's home, to the flood ponds and to the market varies from 0.5 to 15 kilometres. As mentioned above, juvenile *Clarias* are transported to the fish ponds by canoe, wheelbarrow or bicycle. When the destination is outside the valley, cars are used, e.g. for delivery to Kumba which is >300 kilometres

TABLE 3
Labour allocation in fish farming within flood ponds at Santchou, Cameroon

Activities	Men	Women	Children	Extended family members
Pond construction or renovation	*		*	*
Management	*		*	
Removing water during harvesting	*			
Harvesting	*	*	*	*
Removing mud after harvesting	*	*		*
Transportation	*	*	*	*
Selling	*		*	
Smoking		*	*	

Source: Che, 2007.

FIGURE 5
A typical concrete tank for holding catfish juveniles



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away. Prior to transport, the wild seed are kept in 100 litre containers, or in earthen or concrete tanks for up to a month (Figure 5). Water is renewed 1–2 times per day. Fish are fed on corn flour, with care to avoid over-feeding and deterioration of water quality.

In addition to the problems related to cannibalism and stocking fingerlings of similar sizes, key factors determining survival are the renewing of water twice daily and ensuring sufficient accessibility to air for the fish (i.e. use of a wider shallow container, rather than deep one). Another cause of high mortality after stocking appears to be related to the condition in which the fishing was performed. When

fingerlings spend an abnormally long time in the mud during the draining and catching process, up to 100 percent mortality may occur.

AQUACULTURE DEPENDENCY ON WILD SEED

In the Nkam Valley there is no shortage of catfish fingerlings. *Clarias gariepinus* is in high demand and current production from wild capture is sufficient for the existing extensive flood pond aquaculture system. Outside of the valley, however, catfish fingerling demand exceeds supply. With an annual aquaculture production estimated at 330 tonnes nationwide, this demand is close to 1 million fingerlings, which is beyond what is currently availability from the wild (Pouomogne, 2007b).

Although *Clarias jaensis* is the more fished of the two species, farmers prefer *Clarias gariepinus* for its faster growth rate. According to Santchou fishers, *Clarias gariepinus* has been accidentally introduced from upstream hatcheries into the lowland flood ponds where it was not previously found. Most of these hatcheries are now closed due to mismanagement. High transportation costs protect the catfish resources of the Santchou area from major fishing pressure resulting from high demand from outside the valley. Current export outside the valley is mainly due to subsidized aquaculture projects (Table 4). In addition, private fingerling producers are constantly improving their ability to provide quality fish seed at more competitive prices. Some of the PFP sporadically demand broodstock caught from the wild to expand the genetic variability of their base material. These efforts are supported by the research of international

(WorldFish Center, Centre de coopération internationale en recherche agronomique pour le développement – CIRAD) and national (IRAD) institutions (Nguenga and Pouomogne, 2006; Sulem *et al.*, 2007; Brummett, 2007).

Within the valley, the current extensive production system in flood ponds is moving towards intensification and studies are needed to determine

the capability of the native species to sustain competition for food and habitat from introduced *Clarias gariepinus*. Currently, resource management of the catfish fingerlings remains sustainable with stocking of flood ponds being the major demand on the resource.

The introduced *Clarias gariepinus*, which is preferred over the native *Clarias jaensis*, is not heavily represented in the Nkam Valley recruitment. Unless *Clarias jaensis* becomes an interesting candidate for aquaculture, the limited availability of *Clarias gariepinus* seed is unlikely to support the growing aquaculture industry. Investigations on the potential of the local catfish species as a “police-fish” in tilapia pond culture are ongoing (Pouomogne and Mikolasek, 2007).

Access to the collection grounds for catfish fingerlings is governed by strict ethno-sociologic property rights. All revenues from the fishery belong to the fisher and the family owning the fishing area. Investments essentially consist of tools and labour for preparing the fishing area, for collecting the fingerlings and for stocking and marketing the fish. This market chain is currently highly profitable when compared to the profit generated by private hatcheries (Table 5). Margins will decrease with new native fishers demanding access to the fishing grounds. In addition, since the target species (*Clarias gariepinus*) is available in limited amounts in the valley, hatchery-produced seed may not suffer much from competition with wild seed. In the meantime private fingerling producers continue their efforts to improve the quality/price ratio and availability of hatchery-produced catfish fingerlings (Sulem *et al.*, 2006; Sulem *et al.*, 2007).

TABLE 4
Estimated numbers and destination of catfish juveniles fished in Nkam Valley (2006)

Buyers	Quantities ¹	Destination
Fishermen (bait)	2 000	Nkam Valley
Fish farmers (seed)	3 000	Fokoué (Dschang)
	200 000	Santchou (Dschang)
	10 000	Bamenda
	20 000	Kumba

¹ Both *Clarias gariepinus* and *Clarias jaensis*.

TABLE 5
Economics of catfish fingerling collection in Santchou, Cameroon, in 2006

Input	Equipment unit cost (US\$)	Equipment life span (years)	Utilization period	Equipment depreciation (US\$)	Total costs (US\$)
Fixed costs					
Hoes	2.6	3	1	0.6	0.6
Cutlass	3.0	3	1	0.3	0.3
Auger	5.0	5	1	0.3	0.3
Buckets	3.0	2	1	1.2	1.2
Baskets	0.6	1	1	0.6	0.6
Carrier	100	10	1	10	10
Drums	20	10	1	2	2
Total fixed costs					15
Variable costs					
Labour	80				80
Pump hiring	40				40
Total variable costs	120				120
Total costs					135
Total sales revenue¹					2 400
Profit (US\$)					2 265

¹ Catfish fingerlings are sold between US\$0.05 to US\$0.2 per unit.

FISH FEED

Catfish aquaculture producers in Cameroon do not depend on wild-caught feed. Weeds, household organic refuse and, to a lesser extent, agro-industrial by-products such as oilcakes, wheat and rice bran, etc., are generally used to feed the catfish. Single feed ingredients used to feed catfish fingerlings compete with other domestic animals, such as pigs and poultry. These feeds consist of wheat bran and miscellaneous oilcakes, which are mostly farm-made or, to a lesser extent, purchased (Pouomogne, 2007a).

ENVIRONMENTAL IMPACTS OF THE SEED FISHERY

Fingerling collection for aquaculture is usually performed in lowlands inside farm plots after flooding has started to subside. To date, no negative reports, formal or informal, have indicated any decline in the wild stock. Nonetheless, as the wild stock itself is an important local food commodity, adequate fishery statistics need to be collected and monitored systematically to ensure that there is no impact on the stocks as a result of collecting wild catfish juveniles.

Over 95 percent of the fish catch in the Nkam Valley consists of the local catfish species, *Clarias jaensis* (80 percent), followed by the introduced *Clarias gariepinus* (20 percent). Tilapia and the exotic snakehead, *Parachanna obscura*, are among the principal non-target species recorded in the catch data. At Lelem, one fisher reported a recent progressive increase in the percentage of *Parachanna* in his catch indicating that the population dynamics of native species may need further investigation.

No prohibited fishing methods (e.g. fire, poisons, explosives) have been observed in the valley. Foreign commercial fishers using unsustainable fishing gears (e.g. the cast-net “gourah” of Malians, or the beach seine “taro” of the Ghanaians) or extreme levels of fishing intensity have not been observed in the Nkam fishery.

The key strategy for protection of the environment appears to be the full involvement of native fishers in resource management. In the case of the Nkam Valley, ancestral knowledge of the Mbô people, in addition to the national law providing priority in land ownership rights to natives, somewhat guarantees a management control over the fishery resource.

SOCIAL AND ECONOMIC IMPACTS OF FARMING

In each Santchou extended fishing family there are an average of five fingerling collectors and two flood pond fish farmers. The collection of juvenile catfish constitutes a marginal occupation; however, 50 percent of fishers have links with fish farmers outside of the valley and derive substantial income from selling fingerlings. Tradition and pleasure were stated as the motivations for being involved in fingerling collection or fish farming.

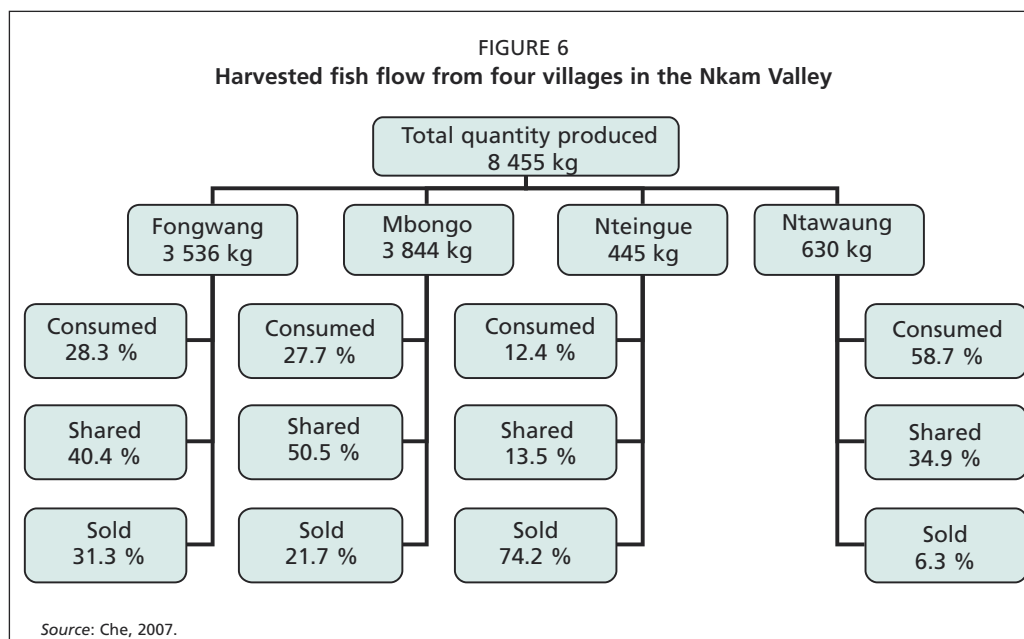
Besides fishing, farmers engage in other economic activities such as crop production, animal husbandry, trading and teaching. Fingerling collection and fish harvesting are performed during the dry season (November–March) along with cocoa and coffee harvesting and farm land preparation. Fishing and aquaculture activities are thus a secondary occupation after agriculture and land animal husbandry.

Most fishers are male (>85 percent), literate (>75 percent attended primary school), and married (70 percent), with an average of eight people living in the house.

Che (2007) documented catfish production from flood ponds in several villages in the Nkam Valley in 2006. The total quantity harvested was 8 455 kilograms which were used as follows (Figure 6):

- direct consumption by the family (31 percent);
- gifts to relatives and friends (34 percent); and
- sale on the market (35 percent).

According to fishers, fish constitutes a major source of protein for the family. Sharing the catch with relative promotes love and friendship among the farmers. Selling



fish for cash increases household incomes and serves to help satisfy demand from other consumers.

Before the emergence of a market for fingerlings outside of the valley, fish were caught for bait, stocking of flood ponds or for direct human consumption. Fish in excess of what could be immediately consumed were often smoked for later utilization. Juveniles were often sold as human food at an estimated price of US\$0.8 per kilogram fresh weight fish. At 25 grams average weight, this is equivalent to US\$0.02 per fingerling.

With the competition introduced by outside buyers, the unit price is currently much higher (up to US\$0.25 for *Clarias gariepinus*). Catfish collectors and dealers are being requested to separate the two catfish species (and to select *Clarias gariepinus*); to grade fish into homogenous sizes; to improve live fish handling and transportation techniques; and to hold fingerlings for sale outside of the wild-capture season. Since the literacy level among fishers is good, most of these challenges are likely to be met.

Traditional annual festivities are organized to pay tribute to the gods of the valley who benevolently provide fishery resources to the Mbô. This special relationship with their gods strongly encourages the Mbô to protect the aquatic environment, limiting catches and designating certain areas within the valley as sacred and not to be fished or farmed.

To address the market demands mentioned above, fishers have gathered into groups and requested technical and financial support from the authorities and from the donor community. One of the activities of the CIP project (see Annex 1) is to train farmers to increase their profitability from the fishing activity. One group of farmer groups (Pêcheurs Et Pisciculteurs De Santchou – PEPISA), has recently overseen the training of six fingerling collectors who are now capable of sorting fish into species and sizes classes.

The case study of four villages illustrates the social issues and income generated from the *Clarias* fishery in the Nkam Valley (Che, 2007):

- i) One of the objectives of the fish farmers in these villages is to have good quality fresh fish for home consumption. The fish consumed by an average fish farmer is almost 10 times the maximum quantity consumed by rural fish farmers in Yaoundé (8.3 kg) (Brummett, 2005; Brummett, Pouomogne and Gokowsky, 2007). The total annual fish consumed in the villages has been estimated at >30 percent of the total quantity of fish produced.



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- ii) An important part of the fish produced is donated as gifts (34 percent). Fishers explain that sharing strengthens relationships between friends and family members. In Santchou, the fish are shared either fresh (10 percent) or smoked (90 percent).
- iii) The selling of fish immediately after harvest is either at the fish farmer's house (>57 percent) (Figure 7), along the road (24 percent) or at the market. Information concerning the harvest and selling of fish is usually communicated verbally to friends and neighbours and to more distant households by sending children with fish to circulate in the area so that people will see and ask where they can buy more. Some of these buyers place their orders before the farmer harvests the fish. In case the fish destined for sale is not all purchased, the remaining fish are prepared for preservation through smoking. The buyers of the fish are restaurant owners, mostly women, retailers and housewives.

Over 28 percent of fish farmers sell fish on a weighing scale, while most sell the fish in heaps or strung on ropes. The prices of fish currently vary between US\$1.00 and US\$2.4 per kilogram (Table 6).

TABLE 6
Fish prices along the chain of custody

	Market location		
	Market	House	Road
Minimum price of fish (US\$/kg)	0.5	0.6	0.7
Maximum price of fish (US\$/kg)	2.4	2.0	2.4
Average price (US\$/kg)	1.46	1.31	1.62

Source: Che, 2007.

The price for pond fish ranges from US\$1.0 to 1.6 per kilogram, with most purchased at the lower end of the scale (Table 7). Demand is thus relatively inelastic as fish are perceived as an inferior good, which is mainly consumed in low income households. The average price of fish is higher when it is sold along the road in comparison to those sold in the farmer's house or at the market.

TABLE 7
Prices and quantities of pond fish sold in the Nkam Valley

Fish price (US\$/kg)	Quantity purchased (kg)
1.0	1549
1.2	760
1.6	600
2.0	90
2.4	10

Source: Che, 2007.

Over the four month season, an individual fingerling collector distributes an average of 11 700 juveniles for a total revenue of US\$1 630.

Although fish collection is a seasonal and secondary activity, after agriculture and animal

husbandry, it can be economically attractive compared to other activities if sustainability managed. Expectations of the farmers are high particularly if they receive training on how best to keep juvenile *Clarias* alive to supply buyers outside the fishing season.

MANAGEMENT AND LEGISLATION

The main laws dealing with the aquatic ecosystems in Cameroon are: Law N° 94/01 of 20 January 1994 on the exploitation and the management of forests, wildlife and fisheries, and Law N° 96/12 of 5 August 1996 on the management of the environment. The preamble of the fundamental law N° 96–06 of 18 January 1996 consecrates the rights of native minorities within their homeland. Together these regulation schemes, if strictly applied, strongly support sustainable management of isolated fisheries, such as the catfish resources of the Nkam Valley. The introduction of alien species (between river basins and from abroad), fishing gear, pollution prevention and other fishery management strategies are dealt with in the existing legislation. A new and revised set of laws to bring the legislation into line with the FAO Code of Conduct for Responsible Fishing (CCRF) is currently under development. This will reinforce the role of research and co-management of fisheries resources, committing the main actors to use available scientific information to improve management of both national and transboundary fisheries (Pouomogne, 2006). Lessons learned in the Nkam Valley (Vander Stuyft and Essomba, 2005; Pouomogne and Mikolasek, 2007) also have relevance to management approaches based on native rights and indigenous knowledge reported in Thailand for the Bangkhen fish culture, Niger in the Tafouka flood ponds and in the Benin whedoes on the Oueme river (Muanboong, 1981; Mikolasek, Mahaman and Siddo, 1998; Imorou *et al.*, 2007).

CONCLUSION

The use of wild-caught *Clarias* catfish for aquaculture purposes is an ancestral practice of the Mbô people in the Nkam Valley. Over the past 10 years, the demand for this seed material outside the valley has created new market opportunities and has led to various *Clarias* resource management modifications in the valley. In 2006, about 0.5 million seed were caught and used for aquaculture, of which about one tenth was exported out of the valley. The main targeted aquaculture species, *Clarias gariepinus*, is second in abundance in the wild after the native *Clarias jaensis*. The Mbô ethnic group have strong regards in the preservation of the fishery resources and have demonstrated instinctive conservation behaviour for the catfish resources. The farmers remain poor but are convinced that they could benefit more from this natural resource.

Research, such as that conducted by the CIP project, may improve the sustainable use of catfish resources in the valley. This programme is based on a better biophysical and socio-technical knowledge of the people and resource which will hopefully lead to improved co-management of the resources (Pouomogne *et al.*, 2006). However, more training of fishers is needed particularly in the handling of wild caught fish to improve quality and survival of fingerlings destined for aquaculture. Most of fishers are poor and unable to implement sustainable management schemes. Adequate credit facilities are necessary to facilitate the purchase of basic fish collection and transportation equipment as well as the construction of short-term holding infrastructure. Due to the strong ethnological and religious links with the aquatic milieu of the Mbô people, legislation reinforcing and protecting their rights may constitute a good strategy to conserve and manage the fishery resource.

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ANNEX 1

The CIP project – Building Innovation in Fish Farming

The main objective of this project is to build through a partnership approach with small-scale farmers a sustainable model of commercial fish farming. The paradigm of this approach highlights local socio-cultural features of the partners involved in the process, alongside with the systemic and complex agronomic knowledge that is needed to fully appraise the diversity of this tropical ecosystem.

The project started in 2004 with a diagnosis survey of fish farming in Menoua division, Western Cameroon Highlands, using a funding of the “Pôle de Compétence en Partenariat-Grand Sud Cameroun” (PCP-GSC). This pole of excellence is constituted of the following partners: IRAD, University of Dschang, University of Yaounde 1, and CIRAD. Following the diagnosis, further funds from CIRAD and the French cooperation allowed to build an action research scheme to address the problems identified. This scheme consists of a research team from the above listed institutions, and two groups of farmers namely “Collectif des Pisciculteurs Intensifs de Fokoué et Penka Michel”, (COPIFOPEM) and “PEcheurs et PIsiculteurs de SAntchou” (PEPISA). Key questions addressed by the team are the followings: (i) how to supply fingerlings and make fish farming a sustainable commercial activity at Fokoué; and (ii) how to improve the capture of wild catfish seed and increase financial gains from capture-based aquaculture at Santchou?

A dozen of scientists and postgraduate students are currently involved in this research programme in cooperation with CIFORD, a non-governmental organization, based at Bafoussam, Western Cameroon. Three senior scientists and two farmers' leaders are animating the research team, namely Dr Victor Pouomogne, Dr Olivier Mikolasek, Dr Minette Tomedi Eyango Tabi, Mr Tila Antoine and Mr Essang Narcisse.

Capture-based aquaculture of mullets in Egypt

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SUMMARY

The use of wild-caught mullet seed for the annual restocking of inland lakes has been known in Egypt for more than eight decades. The importance of wild seed collection increased with recent aquaculture developments. The positive experience with wild seed collection and high seed production costs has prevented the development of commercial mullet hatcheries. Mullet are considered very important aquaculture fish in Egypt with 156 400 tonnes produced in 2005 representing 29 percent of the national aquaculture production. Current legislation prohibits wild seed fisheries except under the direct supervision of the relevant authorities. In 2005, 69.4 million mullet fry were caught for both aquaculture and culture-based fisheries. A parallel illegal fishery exists, undermining proper management of the resources. The effect of wild seed fisheries on the wild stocks of mullet is not well studied. The negative effect of the activity is a matter of debate between fish farming and capture fisheries communities. Data on the capture of wild mullet fisheries shows no observable effect of fry collection on the catch during the last 25 years.

DESCRIPTION OF THE SPECIES AND USE IN AQUACULTURE

Species presentation

Mullets are members of the Order Mugiliformes, Family Mugilidae. Mullets are ray-finned fish found worldwide in coastal temperate and tropical waters and, for some species, also in freshwater. Taxonomically the family is usually treated as the sole member of the order Mugiliformes, but as Nelson (1994) reports, “.... there has been much disagreement concerning the relationships” of this family. Most species commonly reach about 20 cm in total length, but some (e.g. *Mugil cephalus*) may attain 80–120 cm. The head is broad and flattened dorsally in most species. The snout is short and the mouth is small. The gill arches of many species are specialized, forming a characteristic pharyngobranchial organ that has an expanded, denticulate pad used for filtration of ingested material. In many species of mullet, the tiny teeth are positioned on the lips.

The eyes may be partially covered by adipose tissue. There are two short, well-separated dorsal fins, the first with four spines and the second with eight to ten segmented rays. The anal fin is short; with two or three spines, and seven to twelve

segmented rays in adults. The pectoral fins are high on the body, and the caudal fin is weakly forked. The lateral line is absent. The scales are moderate to large in size, with one or more longitudinal grooves. There are two or more pyloric caeca associated with the stomach, which also has a thick-walled, muscular gizzard in most species. Mullet are usually grayish green or blue dorsally, and their flanks are silvery, often with dark longitudinal stripes. They are pale or yellowish ventrally (Harrison, 1999; Nelson, 1994).

Most mullets are found in coastal marine and brackish waters. They are nektonic, usually in shallow inshore environments, such as coastal bays, reef flats, tide pools, and around harbor pilings and in brackish water estuaries, lagoons and mangroves. They usually swim over sandy-muddy bottoms and seagrass meadows, in relatively still waters. They commonly occur at water depths of 20 m but may be found offshore or in deeper waters. Many species are euryhaline and move between marine and freshwater environments of rivers and flooded rice fields. Some species occasionally swim far up river, while a few species spend their entire adult lives in rivers (Smith and Smith, 1986; Cardona, 2006).

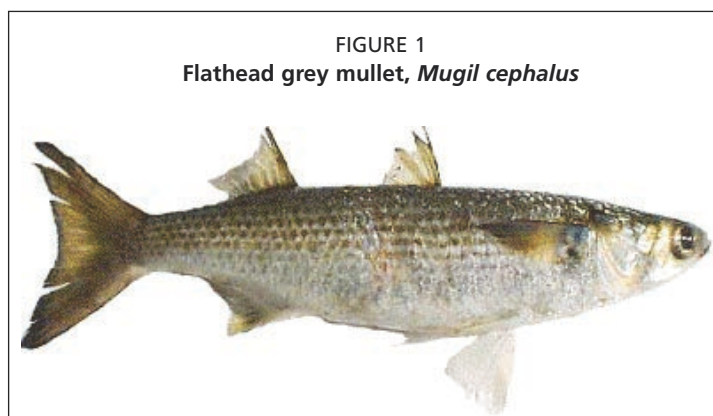
Mullet migrate in large aggregations from their feeding grounds in rivers, estuaries, lakes or lagoons to the sea for spawning in a single spawning cycle each season. Spawning seasons differ according to species and regions. Fecundity is high in all species and is estimated at 0.5–2.0 million eggs per female depending on the size of the adult. Eggs are scattered on the bottom substratum in open waters and left unguarded. The eggs develop at sea and hatching occurs about 48 hours after fertilization, releasing larvae of approximately 2.4 mm in length. When the larvae reach 16–20 mm they migrate to inshore waters and estuaries (Saleh, 2006; Maitland and Campbell, 1992).

Out of the 17 genera and 80 species belonging to the family Mugilidae (Nelson, 1984) only three species are of aquaculture importance. Due to its higher growth rates and market acceptance, the flathead gray mullet *Mugil cephalus*, thinlip mullet *Liza ramada* and the bluespot mullet *Valamugil seбели* are the most commonly cultured species of mullet in Egypt.

The flathead grey mullet, *Mugil cephalus*, is a very important aquaculture species in the Mediterranean, Southeast Asia, Taiwan Province of China, Japan and Hawaii (Saleh, 2006). The species can reach a length of up to 120 cm making it the largest mullet species (Figure 1). Externally, males are difficult to distinguish from females, except for the more slender shape of males when sexually ripening (Virgona, 1995). Their color is olive-green dorsally, with sides that are silvery shading to white ventrally. They have thin lips and the pectoral fins are short, not reaching the first dorsal fin. They have thin lips and the pectoral fins are short, not reaching the first dorsal fin.

The grey mullets, found in coastal waters of the tropical and subtropical zones of all seas, are catadromous, frequently found in estuaries and freshwater environments (Figure 2). Adult mullet have been found in waters ranging from zero salinity to 75 ppt, while juveniles can only tolerate such wide salinity ranges after they reach lengths of

4–7 cm. Adults form large schools near the surface over sandy or muddy bottoms and dense vegetation and migrate offshore to spawn in large aggregations (Eschmeyer, Herald and Hamman, 1983). The larvae move inshore to extremely shallow water, which provides protection from predators as well as a rich feeding ground. After reaching 5 cm in length, the young mullets move into slightly deeper waters (Saleh, 2006).



The species is mainly diurnal and feeds on zooplankton, benthic organisms and detritus. Adult fish tend to feed mainly on algae while inhabiting freshwater. Reproduction takes place in the sea from July to October. Females spawn 5 to 7 million eggs provided with a notable vitellus.

The flathead grey mullet was the first species of mugilidae used for aquaculture. In Egypt, this species has been used for traditional aquaculture and culture-based fisheries since the late 1920s and is still of major importance today also in other Mediterranean countries and Taiwan Province of China (Faouzi, 1936; Saleh and Salem, 2005; Basurco and Lovatelli, 2003).

The thinlip grey mullet, *Liza ramada*, although the second choice in the aquaculture of mullet constitutes the majority of the aquaculture harvest of mullet in Egypt. This species has a lower growth rate than *Mugil cephalus*, but exceeds that of all other Mediterranean mullet species. The availability and abundance of the wild fry of this species as compared to those of *Mugil cephalus* makes it the dominant aquaculture species (Sadek and Mires, 2000) (Figure 3).

Thinlip grey mullet can reach a body length of up to 70 cm. The species is characterized by an elongate fusiform body; slightly compressed from side to side, with a massive short head, flattened above the eyes and with a broad terminal mouth with very small, barely visible, teeth. The upper lips are thin and smooth and the snout is short and blunt. The thinlip grey mullet has two well-separated dorsal fins, the first with 4 to 5 spines. The pectoral fins are placed high on the flanks and the caudal fin is deeply forked. There is no external lateral line and the scales are large and adherent. Scales on the top of the head extend forward to the anterior nostrils and the eye is not covered by a thick adipose lid. At the base of pectoral fin there is a scaly appendix. The colour on the back is grey-dark brown, while the belly whitish-grey often with 6–7 lengthwise stripes (FAO, 1973; Rochard and Elie, 1994).

The thinlip grey mullet is a fast swimmer, leaping out of the water when disturbed. It enters estuaries and rivers for feeding, but spawns in the sea. Juveniles often concentrate

FIGURE 2
Global distribution of the flathead grey mullet, *Mugil cephalus*

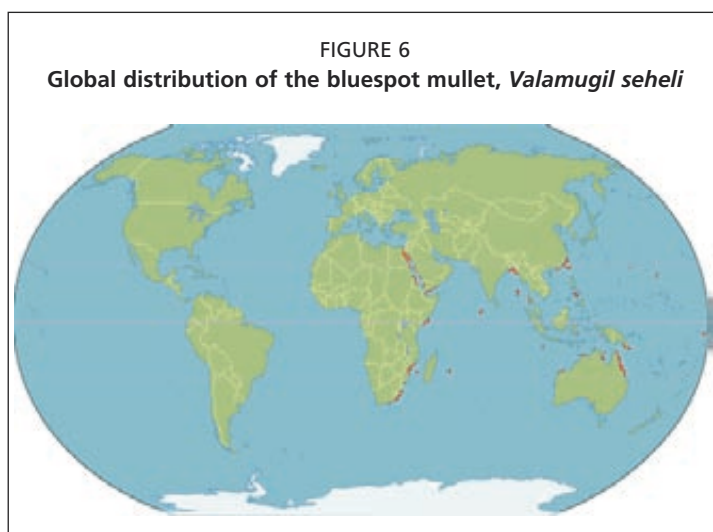
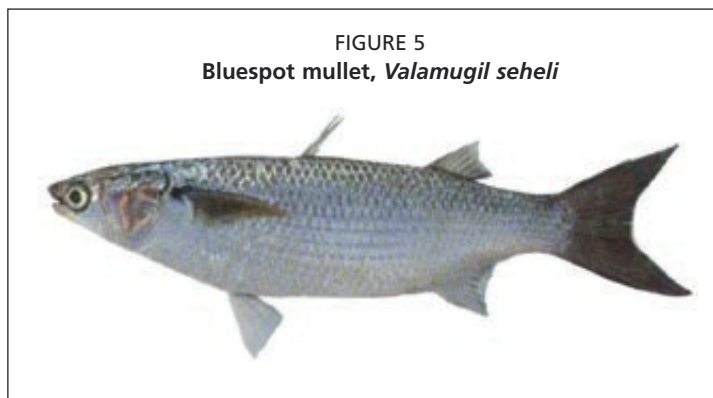


FIGURE 3
Thinlip grey mullet, *Liza ramada*



FIGURE 4
Global distribution of the thinlip grey mullet, *Liza ramada*





in the vicinity of freshwater outflows. It feeds on minute bottom-living or planktonic organisms (e.g. diatoms and amphipods) and also on suspended organic matter. *Liza ramada* is native in the Eastern Atlantic from the coasts of southern Norway to Morocco, including the Mediterranean and the Black Sea (Figure 4) (Wonham *et al.*, 2000).

The bluespot mullet (*Valamugil seheli*) although it has a lower growth rate, fetches a higher market price compared to the other cultured mullet in Egypt. The fish is highly appreciated for its taste and usually consumed at an individual body weight of 120–180 grams. The bluespot mullet can reach a body length of 60 cm. The body is compact, pressed from both sides and the head is small (Figure 5). Adults are bluish brown or green dorsally, flanks and abdomen silvery with a dusky spots on the upper row of scales, giving indistinct longitudinal stripes. The dorsal and upper lobe of the caudal fin has a dark-blue tip. Anal, pelvic,

and pectoral fins are yellow. Pectoral fins are also with dark blue spot dorsally at origin (Harrison and Senou, 1997).

The species usually swims in schools and inhabits coastal waters, but enters estuaries and rivers where it feeds on microalgae, filamentous algae, forams, diatoms, and detritus associated with sand and mud (Harrison and Senou, 1997). The bluespot mullet is found in the Indo-Pacific and the Red Sea all the way south to South Africa; to the east its distribution reaches the Hawaiian and Marquesan islands; north to southern Japan, and to the south to New Caledonia and Norfolk Island (Figure 6). In Egypt, the species is caught mostly from the Red Sea, Gulf of Suez, Suez Canal and the Bitter Lakes. On the Mediterranean coast of Egypt, the bluespot mullet is only caught in the coastal waters of the area extending from Damyitta to the northwest of the Sinai Peninsula.

Mullet fisheries

Mullets are an important component of Egyptian fisheries and are considered as one of the most important cash crops from artisanal fisheries in the numerous lagoons throughout the country. The fish is commonly caught with gill, trammel and veranda nets by artisanal fishers operating in the sea, lakes and coastal lagoons. Based on the statistics published by the Food and Agriculture Organization of the United Nations (FAO) the world total catch of mullet in 2004 was about 261 000 tonnes representing only 0.3 percent of the world fish catch (FAO, 2004).

In Egypt, the 2005 production of mullets was recorded by the General Authority for Fish Resources Development (GAFRD) at 186 000 tonnes, representing about 21 percent of the total national fish production (GAFRD, 2006). Mullet harvest was about 30 000 tonnes in 2005, 81.6 percent of which was from lakes and coastal lagoons.

While production of the capture fisheries slightly increased during 1985–2005, harvest of cultured mullet sharply increased during the last ten years (Figure 7).

The aquaculture harvest of mullet increased from 15 percent of the total aquaculture production in 1980 to 29 percent in 2005 (Figure 8). The percentage of mullet in the catch of the Egypt fisheries increased from 6.1 percent in 1980 to 8.4 percent in 2005 (Figure 9).

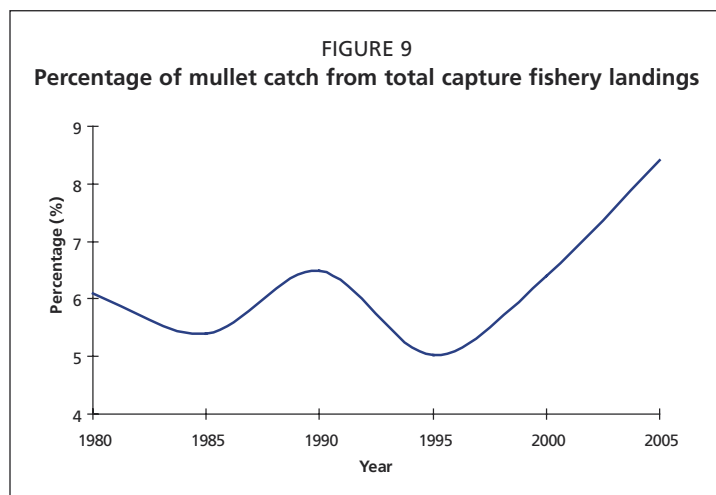
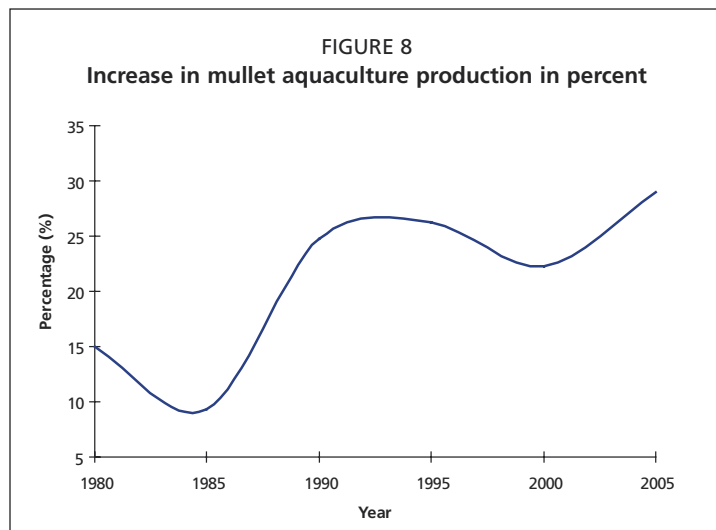
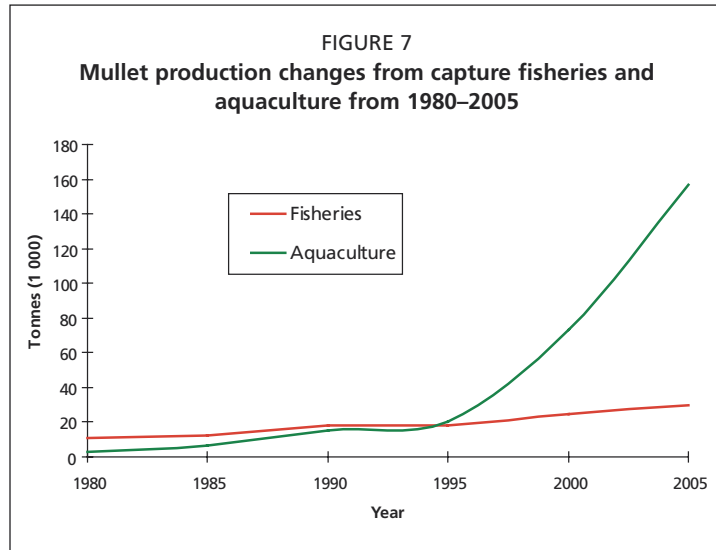
Although there is no accurate published statistics on the catch of the five species of mullet found in Egypt, estimates were found in the landing records in some landing sites. According to these estimates, during the last ten years, the thinlip grey mullet, *Liza ramada*, constituted an average of 58 percent of the catch, while the flathead grey mullet *Mugil cephalus* was only 23 percent and the three other species (*Valamugil seheli*, *Liza aurata* and *Liza saliens*) together constituted the rest.

Mullet aquaculture

Mullet are cultured in a large number of countries worldwide, usually in extensive and semi-intensive pond systems. Egypt has a long history of mullet aquaculture, which was traditionally practised in the “hosha” system in the Nile Delta region for centuries (Eisawy and El-Bolok, 1975). Currently, Egypt is a leading country in mullet aquaculture with a record production of 156 400 tonnes in 2005.

Most mullet aquaculture activities rely on the use of wild seed, e.g. Egypt (Saleh, 1991; Suloma and Ogata, 2006), Taiwan Province of China (Yeh, 1998), the Philippines, Italy (Landoli, 2000), Greece, Israel, Tunisia and Turkey (Sadek and Mires; 2000). Reliance on collection of wild seed was a result of either insufficient supply of hatchery produced seed or its higher price.

Commercial hatchery production of mullet seed is carried out in some countries. Induced spawning and production of fry has been achieved on an experimental and semi-commercial basis in the United States of America and Taiwan Province of China. The production of mullet fry on a limited scale for aquaculture has been reported in



Italy, Israel and Egypt (Saleh, 2006). The development of hatchery production techniques are only practiced commercially for flathead grey mullet as the techniques for seed production of other important species (e.g. thinlip grey mullet) are not yet developed.

In Egypt, mullet fry were first produced in a hatchery near Alexandria through a project in the early 1990s funded by the United States Agency for International Development (USAID). The hatchery production capacity was limited and was capable of producing annually 1–2 million fry of flathead grey mullet. The production cost was high and the fry sold for as much as 15 times the price of wild fry. The failure of marketing the product resulted in shifting the production to species with higher market value and demand, such as the European seabass, gilthead seabream and shrimp. The availability and abundance of mullet fry in the coastal waters of Egypt and accumulated experiences in collecting wild fry developed over more than eight decades are the main reason preventing the development of hatchery production of mullet seed (Saleh, 1991).

In Italy, mullet farming is almost entirely based on extensive techniques, with coastal lagoons and semi-intensive ponds being restocked with wild juveniles. Artificial reproduction trials are currently underway, attempting to establish standard reproduction techniques for mullet (Landoli, 2000).

Mulletts are usually grown in extensive, semi-intensive ponds and netted enclosures in shallow coastal waters. Mullet can be polycultured successfully with many other fish, including common carp, grass carp, silver carp, Nile tilapia and milkfish, and can be reared in fresh, brackish and marine waters.

In Egypt, where most of cultured mullet are produced, pre-farming preparation of ponds is of great importance. Prior to stocking, aquaculture ponds are prepared by drying, plowing and manuring with cow dung. Ponds are then filled to a depth of 25–30 cm and kept at that level for 7–10 days to build up a suitable level of natural feed. The water level is then increased to 1.5–1.75 m and the fingerlings are stocked. Productivity is kept at the required level by adding chicken manure and/or chemical fertilizers. Optimal dissolved oxygen is maintained by the use of various types of aerators, especially after sunset. Extruded feed is supplied to semi-intensive ponds to cover the feeding requirements of both carps and tilapia grown in the same ponds.

The growing season is normally about 7–8 months. If mullet are monocultured, manuring may be sufficient to reach the required feed level. In many cases, mullet have been found to feed directly on chicken manure and good levels of production have been recorded. Growth is checked by sampling, and if growth rates are not as expected, rice and/or wheat bran is added daily as a supplement to the natural feed in ponds. When mullet are reared in polyculture feeding and fertilization programmes usually target the other cultured species while mullets feed on the natural feed, detritus and feed leftovers.

Acclimatized to the appropriate salinity, and stocked as 10–15 g individuals at about 6 200–7 400/ha, a harvest of 4.3–5.6/tonnes/ha/crop can be obtained. In semi-intensive polyculture with tilapia and carp, mullet fingerlings are stocked at about 2 500–3 700/ha together with 1 900–2 500/ha of 100 g common carp juveniles and about 62 000–74 000/ha of 10–15 g Nile tilapia fingerlings. Total harvests are typically 20–30 tonnes/ha/crop of which 2–3 tonnes are mullets. After an on-growing season of 7–8 months in the subtropical region, flathead grey mullet reach an individual weight of 0.75–1 kilogram. Mullet grown for two successive seasons, reaches 1.5–1.75 kilograms. The choice of rearing period and technique depends on market demand and economics.

WILD SEED FISHING

Legal aspects

In Italy, the collection of wild fry is managed by the authorities that issue limited fishing licenses each year between September 16 and December 31 after an assessment

of relevant environmental parameters. Each licensee is allowed a quota of fry catch. Fishing is prohibited at the outlets of rivers and in brackish lagoon channels up to 400 m from the sea. Fishers must be equipped with oxygen supplied transport tanks (Sadek and Mires, 2000).

In Israel, special licenses are required to collect wild mullet fry. The department of fisheries and aquaculture, which also monitors the implementation of the law by means of inspectors, issues these licenses on a yearly basis. No fishing quotas are established (Sadek and Mires, 2000).

Wild fry collection in Egypt is controlled by the Fisheries Law No. 124/1983. According to this law, it is prohibited to fish, collect, handle or transport wild fish fry unless an official permit is obtained from the competent governmental authority (i.e. GAFRD). Fishing for wild fry is also allowed in limited sites supervised and managed by the governmental fry collection stations. Fry collection stations are distributed mainly on the Delta coast of the Mediterranean especially at the outlets of the major agriculture drainage canals, branches of the Nile and the connecting canals of lagoons and lakes to the sea. The mullet harvest at the ten Mediterranean stations is mainly flathead and thinlip grey mullet (98.9 percent of the total mullet fry catch in 2005). Two other stations at the Great Bitter Lake (Suez Canal) and the Gulf of Suez specialize in bluespot mullet.

Fry collection is conducted by teams of private fishers. The team leader and the teams are nominated and checked by the Coast Guard Intelligence before receiving a permit to work in the coastal areas. Each collection station may employ one or more teams. Fishers bring their own fishing gear and other collecting and handling equipment. All the collected fry are brought to the station where the catch is inspected for condition, presence of unwanted species and quantified by estimating the number of fish. Fishers are paid 50 percent of the sale price of the collected fry. The other 50 percent is kept for covering the running cost and maintenance of the stations.

The fry collection stations also act as the distribution and marketing sites for wild fry. Fry price is decided by the government authority and may fluctuate each year according to market demand. Changes in prices are decided and announced by a GAFRD board decree. Collected fry are usually sold directly or transported to GAFRD nursing stations where they are grown out and sold as fingerlings. According to local legislation, fry and fingerlings are sold only to licensed fish farms. Each fish farm is allocated a quota of 6 250–7 500 fry/ha of flathead or thinlip grey mullet or up to 12 500 fry of bluespot mullet. This quota system has created numerous management and control problems. In fact many mullet farmers state that the quota decided by the authority is much less than what is effectively required for a profitable production. The government authority, on the other hand, considers the quota to be more than enough if the farmers carry out the recommended handling, acclimatization and nursing procedures that prevents heavy losses of fry. Mulletts are usually produced in semi-intensive polyculture with other fish where it only constitutes less than 20 percent of the reared stocks.

The development and expansion of aquaculture was motivated by high profitability that attracted many agriculture land owners, especially those with newly reclaimed land of marginal profitability, to shift to aquaculture. Due to the shortage of water and agriculture land resources in Egypt, the transformation of agriculture land to aquaculture is contrary to the relevant agriculture, irrigation and fisheries legislation. In a recent field survey carried out by GAFRD, Ministry of Environmental Affairs, and the Aquatic Police and Land Reclamation Authority, it was reported that 36 400 hectares of reclaimed agriculture land were used for aquaculture activities in two Delta Governorates. The 2005 GAFRD statistical yearbook estimated the total area of this activity at 55 200 hectares representing about 52 percent of the total aquaculture area of the country. According to current legislation, GAFRD cannot license such farms.

These farms are not allowed to purchase seed from the governmental hatcheries or fry collection stations and they can only depend on illegal sources for their stocking needs. The recorded mullet production from such farms was 82 000 tonnes in 2005 (GAFRD, 2006) representing about 47 percent of the production of cultured mullet in the country.

As a result, fish farmers seek other sources of seed supply. This has created an illegal activity of fishing and marketing of wild-caught seed by gangs of illegal fishers. These unlicensed fishers sneak into the coastal areas or banks of drainage canals, well equipped with seine nets, light boats and pickup trucks. The illegally harvested fry are transported very early in the morning along country roads to a fry market in the fish farming areas where they are sold by the thousands. The number of fry collected through this illegal activity is not recorded and is uncontrolled. The size of this illegal trade is believed to be very large and the number of collected fry may exceed those collected through the official stations.

Fishing techniques

Mullet are known to have a seasonal breeding migration when large shoals of adults leave lakes, coastal lagoons and rivers and move to breeding grounds in the open sea. Breeding seasons differ according to species and regions of the world. Hatched larvae drift with surface water currents (Rossi, 1986) and then swim in large aggregations towards the shallow coastal waters to reach the rich feeding grounds in the estuaries and coastal lagoons. Mullet seed reach the estuaries and shallow coastal waters as fry that are 12–20 mm long. Mullet fry are fished as they reach the coast or from the inlets of the coastal lagoons and openings of agriculture drainage or irrigation canals.

In Egypt mullet have been commercially fished for restocking saline inland lakes since the early 1920s (Wimpenny and Faouzi, 1935; Faouzi, 1936). The Suez Canal, its adjacent lakes, the Nile effluents and discharge canals leading to the Mediterranean have been the main source of the seasonal mullet and other euryhaline fish fry catches (El-Zarka and Kamel, 1965). The early techniques used for commercial wild fry collection were described by El-Zarka, El-maghraby and Abdel-Hamid (1970). The gear was made from mosquito nets fitted to a rectangular metal frame with a wooden roll bar fixed to the front edge of the frame and pushed in the shallow coastal water by a team of three fishers. The reported fry catch of such gear was about 20 000 fry per hour. With the increased demand for fry in the late 1990s, shoals of fry were collected in coastal water using larger fine seine nets (Figure 10).



The commonly used seine is 50–150 m wide and 2.25 m deep. Netting material is made of strong monofilament threads of synthetic fibers with 1 mm stretched mesh size (Figure 11). The material is manufactured mainly for household use, window and fishpond screens. The purchased material is prepared by the fishers by fixing cork and lead lines, side wooden bars and pulling ropes. Scoop nets are also used to collect fry from the agriculture drainage canals especially near the outlets of pumping stations leading to the sea (Sadek and Mires, 2000).

Collected fry are scooped from the fishing net by small fine hand

nets, carried in buckets filled with seawater and kept in *hapas* or shore aggregation tanks for a few hours. At this point fry are sold to customers or moved to transport trucks to be sold at the fish farms. Fry are also transported by trucks to separate nursery units, or nursery facilities in grow-out farms to produce fingerlings.

Fry collection activities are carried out by artisanal fishers. Techniques are simple and the gear is developed from locally available materials. The highest cost is for the seine net. The cost of fabric is about US\$60 and about US\$50 for cork, ropes and lead. A light wooden boat can sometimes be used to stretch the net in deeper water (Figure 12). Such a boat can cost US\$200–250 but it is used for other activities beside the seasonal and temporary fry collection. In an interview with a team leader working with the governmental station near Port Said, the overall cost of gear, equipment and fees were calculated to be around US\$500–520 for each fishing cycle of 3–4 months. The season of mullet fry collection extends to 10 months in three cycles each year.

Annual data on mullet seed collection in Egypt is found in the GAFRD records for the last three decades. The annual catch of mullet fry during the early 1980s was around 50 millions per year (53.7 million in 1980). In 1985, the total number increased to 83.2 million fry. Most of the collected fry (64 percent) were used to stock inland lakes (culture-based fisheries) the rest was used for aquaculture.

The magnitude of mullet fry collection activities varied greatly with the fluctuation in demand associated with the status of aquaculture development. Increase in the demand for seed was associated with the rapid development of aquaculture in the 1990s (Figure 13). The official record for the last 10 years is not comprehensive, as the illegal fry catch

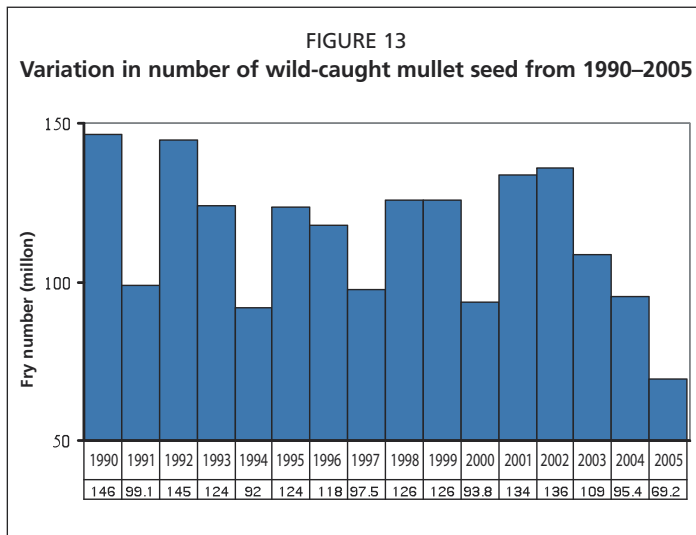
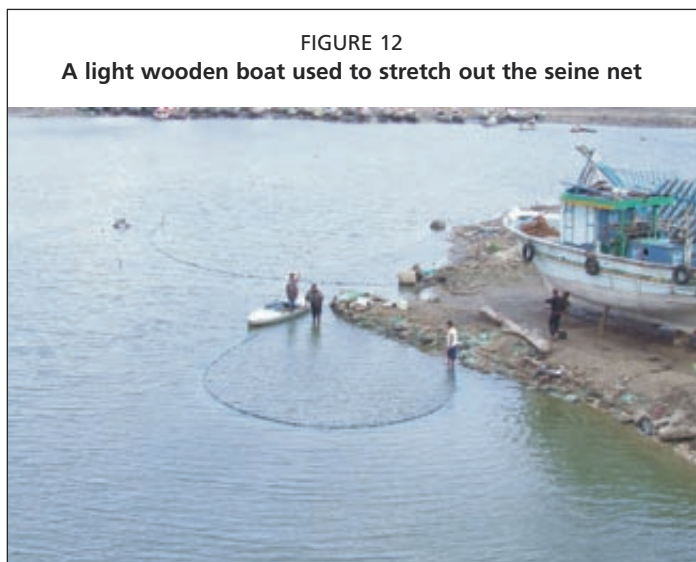


TABLE 1
Recorded and estimated mullet seed catch, fish production, and numbers of utilized seeds in licensed and unlicensed farms

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Production – licensed farms (1 000 tonnes)	13.6	9.7	13.6	10.4	22.7	21.6	46.8	62	67.3	74.5
Production – unlicensed farms (1 000 tonnes)	6.5	6.4	14.8	32.6	57.6	66.6	66.2	73.6	65.4	82
Fry used in licensed farms (million)	41.0	35.3	36.4	38.3	44.8	85.8	102.4	75.5	64.6	65.0
Estimated fry used in unlicensed farms (million)	19.6	23.3	39.6	91.8	113.7	264.6	144.8	89.6	62.8	71.5
Fry used for restocking lakes (million)	77.0	62.0	89.6	87.7	49.0	48.2	33.6	33.5	30.8	4.4
Estimated total fry collected (million)	137.6	120.8	135.6	217.8	207.5	398.6	280.8	198.6	158.2	140.9

generally is unreported. According to GAFRD illegal fry collection has increased sharply during the last five years as a result of the unlicensed fish farms built illegally on newly reclaimed agriculture land.

The recorded catch of mullet fry during the past 15 years varied between 90–145 million fry per year with the highest catches in 1990 and 1992 when about 146 and 145 million fry were collected, respectively. Starting from 2003, fry catch began to decline. The sharp decline in 2005 was due to the reduced number of legally caught mullet seed used in restocking inland lakes, from 32 million in 2004 to about 4 million in 2005 (GAFRD, 2006). The recorded number of fry used for production on licensed farms can be used to extrapolate the number of fry used on unlicensed farms, as both apply the same technology and management systems.

In 1996, mullet production from unlicensed farms was estimated at 6 500 tonnes representing approximately 32 percent of the total cultured production, while in 2005 the harvest increased to 82 000 tonnes representing 52 percent of the annual output.

Table 1 show the recorded mullet production from both licensed and unlicensed farms from 1996 to 2005 along with the total recorded number of fry (all three species) officially collected during the same year. The table highlights the fact that mullet production is not related to the number of fry utilized.

Production from 2003 to 2005 increased even though the number of fry utilized dropped considerably. During this same period the government increased the price of fry from US\$3.5 to 17.6 per thousand resulting in both positive and negative effects. On the positive side, it led to an improvement in fishing, transport, handling and acclimatization techniques and a more responsible and rational utilization of the resources. On the negative side, the increased profit from the sale of fry encouraged additional illegal fry fishing.

Table 2 indicates the change in the relative importance and number of collected seed from each of the three species farmed in Egypt. The data shows that the catch of *Liza ramada* seed was always the highest at about 59 percent of the total mullet seed collected in 2001 to over 79 percent in 2005. This was also the case in Greece where seed of this species was the most abundant and represented over 54 percent of mullet fry found (Koutrakis, 2004).

TABLE 2
Changes in the relative importance and number of collected seed of different mullet species

Year	<i>Liza ramada</i>		<i>Mugil cephalus</i>		<i>Valamugil seheli</i>		Total (millions)
	Fry No. (million)	%	Fry No. (million)	%	Fry No. (million)	%	
2001	78.9	58.9	40.6	30.3	14.5	10.8	134
2002	101.5	74.6	15.4	11.3	19.3	14.2	136
2003	76.0	69.7	20.9	19.2	12.1	11.1	109
2004	66.6	69.8	12.8	13.4	16.0	16.8	95.4
2005	55.1	79.4	8.0	11.5	6.3	9.1	69.4

The percentage of *Mugil cephalus* declined during the same period from about 30 percent in 2001 to 11.5 percent in 2005 whereas the catch of *Valamugil seбели* was more stable. The decline in the catch of *Mugil cephalus* in 2002 was balanced by an increase in the catch of *Liza ramada* seed from 79 million in 2001 to a record of 101.5 million in 2002. Two reasons have been identified for the decline of *Mugil cephalus* fry. The first was the increased production of dried mullet roe and the second that most of the illegal seed fishing activities concentrated on the higher priced flathead grey mullet.

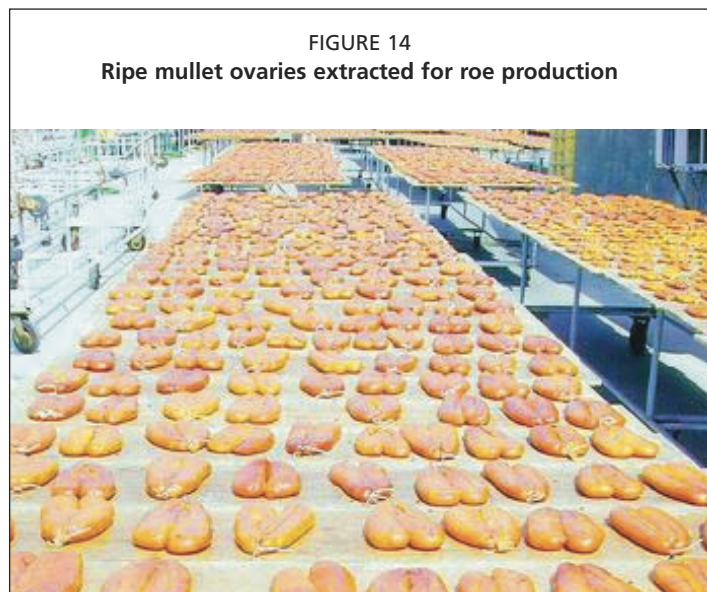
Fishing mullet to extract the ovaries is an old practice, which is expanding rapidly in the Mediterranean, Asia and the United States of America (Figure 14). The activity is a real threat to the species considering the high fecundity of the flathead grey mullet. Each migrating ripe female killed to extract the ovaries means losing 2–4 million eggs and at least many hundreds of thousands of seeds.

Mullet seed collection is carried out by men as are all other commercial fishing activities in Egypt. Women, on the other hand, are mainly involved with the manufacturing and repairing of the fishing gear. The mullet seed fishery is practised by resident fishers living in the coastal areas near the lakes and coastal lagoons. The activity is territorial and each group of fishers works in their area without intruding into neighboring areas.

Utilization of wild fry was known to be associated with a high seed mortality attributed to trauma of rough handling during collection and transport. As a result of effects initiated in the mid-1920s Egyptian experts attained extensive experience in handling mullet fry on a large-scale that dramatically reduced the losses during handling.

Fry collected using different fishing gear are usually retrieved in small buckets filled with seawater and collected in *hapa* cages or shore tanks. These aggregation tanks and *hapas* are also used to inspect the catch and remove unwanted species or traumatized fry. During sale, fry are scooped by hand nets, counted and emptied into polyethylene bags, insulated pickup trunks or loaded onto specialized fry transport trucks (Figure 15). Fry tanks (usually 1 m³) can carry up to 15 000 fry for a transport period of up to 4 hours and densities vary according to the travel distance. Cooling with ice bags is usually applied during summer.

If oxygen inflated bags are used, these can be carried on any vehicle. Owners of small farms usually carry 4–6 bags in the trunks of their cars. Each of the fry bags can carry up to



2 000–3 000 fry and are used for short distance transport (<2–3 hours). The bags are usually filled with 1/5 water and 4/5 compressed oxygen. If the bags are carried by pickup trucks, they are usually protected from the sun with rice straw mats sprayed with water for cooling. Fry are sometimes transported in plastic bags by motor boats if the farming site is near a water body.

Upon arrival, fry are usually acclimatized to the receiving pond environment. For transport in plastic bags, the bags are first immersed in the ponds and the contents eventually emptied. If transport was by pickup trucks, fry are first collected into plastic buckets. Dead and weak fry are usually removed and the number of stocked fry in each pond is recorded. If transport was by specialized trucks, a large volume of transport water is substituted with pond water before releasing fry into ponds.

High fry mortalities are reported in many farm sites as a result of insufficient acclimatization. In a three year study on the utilization of wild mullet fry for restocking inland lakes in Egypt (Kleijn, 1988), losses during transport (6–8 hours) varied between 0.9–1.4 percent. In the same study, the mortality of fry during four months in nursery ponds was up to 35 percent.

Saleh (1991) reported that mortality rates of 96 percent of the transported fry may occur during the first 7 days if the fry are directly transferred from seawater to the nursing ponds with a salinity level <2.6 ppt. Mortality was reduced to 6 percent through gradual (6–8 hours) acclimatization.

High losses can also be expected during the nursery period due to inadequate pond preparation and management. Most of the losses are associated with predation by other fish (African catfish, *Clarias gariepinus*, and the red bellied tilapia, *Tilapia zilli*) commonly found in poorly prepared ponds. Large losses also occur in heavily fertilized ponds due to oxygen depletion and during the harvesting of the fingerlings.

AQUACULTURE DEPENDENCY ON WILD SEED

Commercial aquaculture of mullet in Egypt and other producing countries relies exclusively on wild-caught fry even though hatchery techniques have been successfully developed (Saleh, 1991; Landoli, 2000; Yeh, 1998; Sadek and Mires, 2000; Suloma and Ogata, 2006). The high cost of hatchery-produced seed compared to wild fry, and the interest of most commercial hatcheries to produce seed of higher valued marine species (e.g. European seabass and/or Gilthead seabream), are the main reasons for continued reliance on wild seed.

Fishing wild fry for aquaculture has always been a matter of debate between environmental groups, capture-fisheries communities and fish farmers. The increasing rate of seed collection in the mid-1990s was considered as a major threat to the capture fisheries. Artisanal fishing cooperatives organized extensive campaigns against wild seed collectors. This legal practice was also considered as an unjustified government policy in support of wealthy fish farmers at the expense of the larger, poorer fishing community. Environment groups believe that wild seed collection will reduce stock recruitment even though the authority claimed that the number of collected fry will have a negligible effect to the wild mullet population. The argument is based on the fact that mullet are characterized by a very high fecundity, which means that the number of collected fry for aquaculture is a very small fraction of the seeds produced by these fish. It is also claimed that the fry losses for aquaculture are considerably less than that from natural predation. This debate is not yet settled, but the stability of mullet fisheries over more than a decade in spite of a growing aquaculture industry has reduced the level of opposition even though the capability of the wild resources to cover the future growth of the sector is unknown due to limited scientific data.

Hatchery-produced mullet seed are not likely to become available in the near future in Egypt and aquaculture will continue to rely on wild seed. The cost of hatchery seed in Egypt was found to be very near or even sometimes higher than that

for other locally cultured marine species such as the Gilthead seabream, European seabass, meager and shrimp. As a result, unless a total effective ban on wild seed collection is imposed, mullet aquaculture in Egypt will continue to depend on wild seed.

FISH FEED

The success of mullet aquaculture is also a result of its feeding habits. Mullet are usually farmed in polyculture with other fish species in earthen ponds. Enhancing natural food production in the ponds through artificial fertilization is important as this reduces considerably the requirements for manufactured feed. In the Egyptian polyculture system, natural food covers 25–50 percent of the food requirement of the cultured fish (tilapia, carps) while the farmed mullet depend totally or to a very large extent on natural food (Figure 16). Cultured mullet are sometimes supplied with wheat or rice bran during the late nursery stage or when cultured as the main component of the fish stocks.

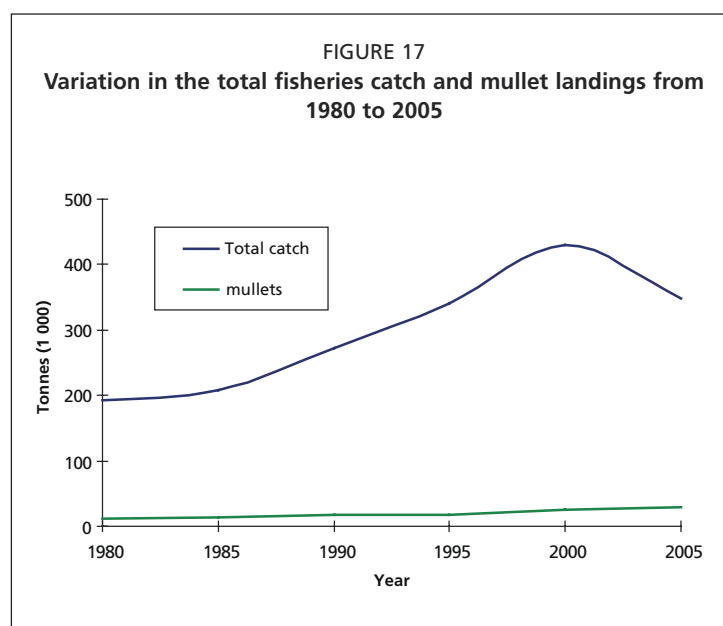
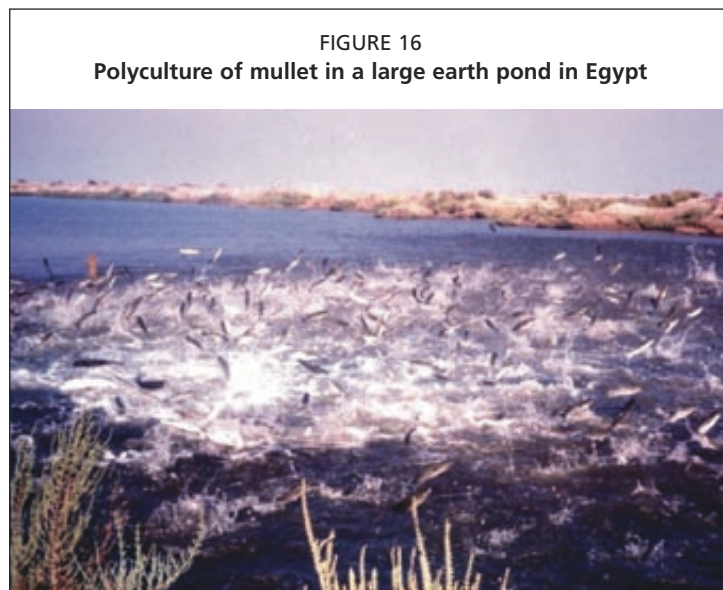
The fish feed industry is well developed in Egypt where more than 450 000 tonnes of different forms of formulated feed (mostly extruded pellets and powder mixes) are produced annually (GAFRD, 2006). Chicken manure is also used successfully as feed for mullet in nursery and on-growing ponds.

ENVIRONMENTAL IMPACT OF MULLET SEED FISHERY

Although the collection of mullet seed in Egypt goes back many decades, there is no published scientific study on the impact of this activity on the wild stocks. Most of the available information is based on comparing mullet catches in relation to the recorded number of collected fry. The extrapolated results are of limited value as landing estimates are not accurate enough (e.g. illegal catches are excluded) to evaluate possible impacts of wild seed collection.

Figure 17 compares total fish landings in Egypt with the landings of mullets over a 25-year period and clearly indicates that mullet catches have not decreased. Based on these figures it seems that the mullet fishery is not affected by the wild seed fisheries.

Mullet seed fishing is a seasonal activity and fishers tend to know when the fishing grounds are likely to receive large volumes of mullet fry of each species. During these periods, fry of the target species are found in large shoals and, since



the presence of unwanted species greatly reduces the market price of mullet seed, the fishers carefully inspect their catch and return unwanted fish species, if any, back to the sea.

The presence of other species with mullet seed was studied the mid-1980s (Kleijn, 1988). Kleijn (1988) showed that 87 percent of the collected seed (sample size 78 000 fry) were mullet, 6.9 percent ribbonfish (*Lepidopus* sp.), 3.1 percent silverside (*Atherina* sp.) and halfbeaks (*Hemiramphus* sp.) and 2.9 percent *Gammarus* sp.

Finally mullet seed fishing is carried out in shallow coastal waters on sandy and muddy substrates. The impact of the fishery on bottom biota has not been evaluated, however, the impact is likely to be minimum compared to impacts of fishing activities on other sensitive ecosystems (e.g. coral reefs).

SOCIAL AND ECONOMIC IMPACTS OF MULLET FARMING

Social impacts

Although a small number of people are involved in seed collection, it is an important economic and social activity. The rapidly growing aquaculture industry in Egypt depends largely on mullet production, which accounted in 2005 for about 29 percent of the production and 48 percent of the market value of cultured fish (GAFRD, 2006). Aquaculture presently employs more than 300 000 persons and supports an additional 450 000 jobs in complimentary activities (fish feed production, transport, marketing, processing, etc.). Limiting or discontinuing mullet production will affect the economy of the semi-intensive aquaculture industry, a critical component of Egyptian aquaculture.

The development of pond aquaculture created a new competitive seed market. Before the mid-1980s, most of the wild-caught seed were used by the government for restocking programmes of inland lakes. Fry were collected at a single government station near Alexandria from 1926–1984. During the early days of aquaculture development, common carp and mullet were the major cultured species in Egypt while tilapia was considered only a bycatch crop accounting for 10–25 percent of the production.

The increase demand for mullet seed resulted in the establishment of nine additional fry collecting stations along the Mediterranean coast from 1986–1987, marking the beginning of organized mullet fry fisheries.

Mullet seed collection is carried out by groups of artisanal fishers which often include people from the same village or district and frequently involve members of the same family. Each group may consist of 6–10 persons working under a team leader who generally oversees more than one group. In 2005, 460 registered fry collecting fishers were working in eight major government stations (6 in the Northern Delta and two in Suez Canal region).

Fisher groups work grounds allocated by the authority in their home range and supervised by the government fry collection station in the area. The team leader is usually someone with a strong influence on the group members and is usually a head of a local cooperative or a large fishing family. The team leader is responsible for nominating group members, collecting fishing licenses and other documents required by the competent authorities to issue the work permits. The team leader is also responsible for delivering the collected seed through the official channels and is in charge of bookkeeping and recording all catch.

The earnings of each group member differ according to their role. The work is divided into three tasks; the first is the fishing operation itself, which requires 4–6 fishers to spread and pull the seine net. The second task involves the transport of the buckets which requires 1–2 younger, less skilled persons. The third task is the sorting, cleaning and counting the catch, which is usually done by the most experienced in the group. This latter task involves the removal of weak, injured, dead or unwanted

species from the *hapa* or shore tank and counting the fry. The money earned by the group is divided into equal shares; members of the third group gets three shares per person, while those of the first group get two shares per person and members of the less skilled second group get one share per person.

Illegal gangs of fishers are involved in fry collection mostly outside the territory covered by the authorized teams even though they frequently invade these territories to find better stocks. Illegal fishers are well organized and usually reach the fishing ground in the early hours of the morning before the arrival of the authorized fishers and working in teams of four

to five persons. The collected fry are stocked in pickups and sold directly to the owners of unlicensed farms or to fish farmers who are not satisfied with their government allocated quota (Figure 18). The number of fishers working in the illegal seed fisheries, transport and marketing is not known.

A group of seed fishers can earn between US\$1–1.2 million/year. This money is tax free and is distributed by the team leaders according to the share distribution system described above. Seed fishers, although rich, are considered as lower middle class by city people based on their education and cultural levels, but they are considered as the elites in their lagoon fisher communities.

Economic issues

Aquaculture is the fastest growing fisheries sector in Egypt and mullet aquaculture is an important contributing component (Salem and Saleh, 2004). Land-based aquaculture in Egypt is labor intensive and employs a large number of people with different technical skills. This economic activity is characterized by high returns on the initial investment even though profits have declined following the rise in production during the last five years. This type of aquaculture has prompted an important restructuring of the fish farming communities and production systems.

Traditional aquaculture was practised by fishers over extensive wetlands and brackish water lakes owned by the government. The activity was primitive; it required a low investment input and generated a low production per unit area. Furthermore, the work was carried out exclusively by members of the family, with limited numbers of part-time workers were hired during harvest or preparation for the new season. As a result of extension programmes supported by the government and the increased demand for fish, aquaculture was rediscovered by a new generation of well educated investors with professional backgrounds. As a result, technically advanced aquaculture systems were introduced, such as semi-intensive and intensive pond aquaculture on traditional aquaculture land or purchased from the government. These lease arrangements usually included an agreement to pay a certain amount of money to the inhabitants of the farmed areas, which in turn was used by traditional farmers to modernize their own farming activities.

The development and growth of aquaculture sector in Egypt was not possible without mullet as an important cash crop. Wild seed fisheries are a year around activity. The sequence of spawning times for the different target species (mullet, meagre, European seabass and gilthead seabream) makes fry collection a full-time activity

FIGURE 18
A pickup truck carrying illegally caught mullet fry



and involves numerous groups of fishers. Based on official data each fisher earns US\$1 900–2 700/year, an income higher than the average annual per capita income in Egypt (about US\$1 700 in 2006).

MANAGEMENT

Aquaculture and fisheries activities in Egypt are regulated by the Fisheries Law No. 124/1983. The sector is administered by the General Authority for Fisheries Resources Development (GAFRD), established by Presidential Decree No. 190/1983, under the Ministry of Agriculture. According to Article 18 of the above law, fish fry may not be collected or removed from the sea, lakes or other water bodies except with an official permit issued by GAFRD. The violation of Article 18 may provide grounds for imprisonment of 3–6 months or a fine up approximately US\$90. The sentence is more severe in case of repeat violations.

Application of the law somewhat guarantees control of the activity and rational utilization of the resources. The increase in illegal seed fishing indicates a weakness in enforcement which is divided between the Ministry of Interior and Ministry of Defense. The Coast Guard (Ministry of Defense) is in charge of enforcing the law in coastal areas while the Aquatic Police covers other water bodies.

CONCLUSIONS

- Collection of wild mullet seed for aquaculture and restocking of lakes is an old practice known for many decades in Egypt and other Mediterranean countries.
- Flathead and thinlip grey mullet are the most important aquaculture species.
- Egypt is the major producer of cultured mullet with a production 156 400 tonnes in 2005.
- In most producing countries, mullet aquaculture depends exclusively on wild seed.
- Hatchery production of mullet seed is carried out in some countries, but its commercial production in Egypt has proven not to be economically viable.
- Wild fry fisheries are legally managed in most of the countries, and this activity is also supervised in Egypt by the competent authorities.
- Illegal wild seed fisheries in Egypt result in resource management problems.
- Demand for mullet seed increased greatly in Egypt during the last ten years as a result of the expansion of aquaculture.
- The official recorded numbers of wild-caught mullet seed in Egypt decreased during the last four years, at the same time that production of cultured mullet has increased.
- Increase in the price of mullet seed resulted in more rational utilization of the resources and a reduction in handling losses.
- The fast growing activity of fishing ripe flathead grey mullet females for roe production in many countries may affect the future of the wild stocks.
- Mullet is an important cash crop for the aquaculture industry in Egypt.
- There is no reliable scientific information to ensure proper management of the mullet seed fisheries in Egypt.
- The present Egyptian legislation is considered adequate; however, enforcement may not be sufficient to control the fishery.
- Dependence on wild seed does not provide for long-term planning of the sector and hatchery production of mullet seed may be necessary.
- The government may adopt a policy of subsidizing hatchery production of mullet seed followed by a ban on wild seed fisheries to encourage hatchery development.

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Capture-based aquaculture of wild-caught Indian major carps in the Ganges Region of Bangladesh

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INTRODUCTION

Background and country context

Bangladesh is a riverine floodplain country with over 700 small, medium and large rivers and three major river systems (the Ganges, Brahmapura and Meghna) that originate from the Himalayan chain, cross the country and then join before emptying into the Bay of Bengal. The rivers cover over 24 000 km which constitutes approximately 6 percent of the total area of the country. Apart from rivers, there are numerous natural wetlands in the form of canals, *beels*, *haors*, *baors*¹, mangrove swamps and lands which flood seasonally for 5–6 months of the year. The wetlands range from 7.5 to 7.8 million hectares (Table 1) (Nishat, 1993). The floodplains are very rich in natural productivity and support a diverse flora and fauna, among which fish is considered the most important natural resource, as it supports the livelihoods of millions of inhabitants, including many of the rural poor.

Bangladesh has a humid climate with three broad seasons: warm summer (March to May), wet monsoon (June to October) and cooler winter (November to February). Rainfall is abundant and ranges annually from 140–400 cm, with over 80 percent received during the monsoon months. The temperature during the summer varies from 35.0–37.5 °C, reaching 43 °C at times, while in winter the temperature ranges from 17.5–24.0 °C, falling as low as 4.5 °C in some locations.

Monsoon flooding strongly influences the biophysical and socio-economic functions of the country. With the onset of rains in April–May,

TABLE 1

Area of seven types of water bodies in Bangladesh

Types of water bodies	Area (ha)
Large reservoirs	90 000
Coastal shrimp farms	141 000
Permanent rivers and streams	480 000
Estuaries and mangrove swamps	610 000
Shallow lakes and marshes	120 000–290 000
Ponds and ditches	300 000–400 000
Seasonally flooded lands	5 770 000
Total	7 511 000–7 801 000

Source: Nishat, 1993.

¹ *Beels* are floodplain lakes, which may hold water permanently or dry up during the winter season; *haors* are depressions in floodplains located between two or more rivers, which function as internal drainage basins; and *baors* are oxbow lakes (Hasan and Ahmed, 2002).

the water level in the river systems start to rise, and gradually overflows the river banks and inundates nearly one third of the country for 5–6 months. The river water starts rising even before the monsoon, because of the rise of temperature that causes snow melt in the Himalayas.

The warm temperatures and high rainfall, coupled with numerous rivers and wetlands that are rich in nutrients, have endowed the country with rich fisheries resources. The wetlands in Bangladesh support around 265 species of freshwater bony fishes representing 154 genera and 55 families. There are also more than 30 species of prawns and shrimps in freshwater systems and coastal waters. Of the 265 freshwater fish species, four species of Indian major carps are commercially important, and make up a significant proportion of both the inland capture and culture fisheries production.

Information availability on capture-based aquaculture

Although there is an established practice of collecting major carp spawn from rivers to supply seeds to the carp aquaculture industry, this aspect of the fishery has not been well documented. However, studies have been conducted on some of the main aspects of carp stocks in the wild, and on breeding behaviors and spawn collection, by different research projects and by the Bangladesh Fisheries Resources Survey Systems (BFRSS) of the Department of Fisheries (DoF).

Most of the available information is focused on the biological aspects of carp, their migration and breeding behaviors, spawning times and grounds, and on spawn collection and nursery rearing. Since 1984, the BFRSS have been collecting data on major carp spawn collection from the main river sources. This database includes spawn collection centers by river systems, number of nets used, collecting period (season), quantity caught, price, and the number of people engaged. However, there is no mention of the socioeconomic aspects of the people engaged in the wild-caught spawn fishery, nor of the marketing and distribution systems for the wild-caught spawn. The environmental implications of collection of major carp spawn from the wild are poorly documented.

Some literature highlights the stock of major carps and spawning-related information, indicating concern over declining carp stocks in the wild and making recommendations. Tsai and Ali (1985) analysed the BFRSS data, and found no significant adverse impact of carp spawn collection from the wild on the natural stock of major carps in Bangladesh.





There has been extensive work on the Halda River stock of carp in southeast Bangladesh, the only main carp spawning grounds in the country, and from which fertilized eggs are collected. Changes in the course of rivers made by the Bangladesh Water Development Board (BWDB) resulted in negative impacts on carp spawning grounds. The harvest of broodstock fish from Halda River, especially while they migrating to their spawning grounds, has negative impact on the wild stock. The other stock of major carp spawn is in the upper reaches of the rivers outside Bangladesh, a location from which spawn, rather than fertilized eggs, are collected.

MAJOR CARP FISHERY IN BANGLADESH

General information on the carp

The four species of carp found in the waters in Bangladesh are grouped together as Indian major carps: catla (*Catla catla*), roho labeo or rui (*Labeo rohita*), mrigel (*Cirrhinus mrigala*) and kalibaush (*Labeo calbasu*). Although the age of maturity for spawning varies by species, all require at least two years to attain sexual maturity and spawning ability; rui require at least two years, mrigel requires 2–3 years, and catla and kalibaush mature at three years (Table 2).

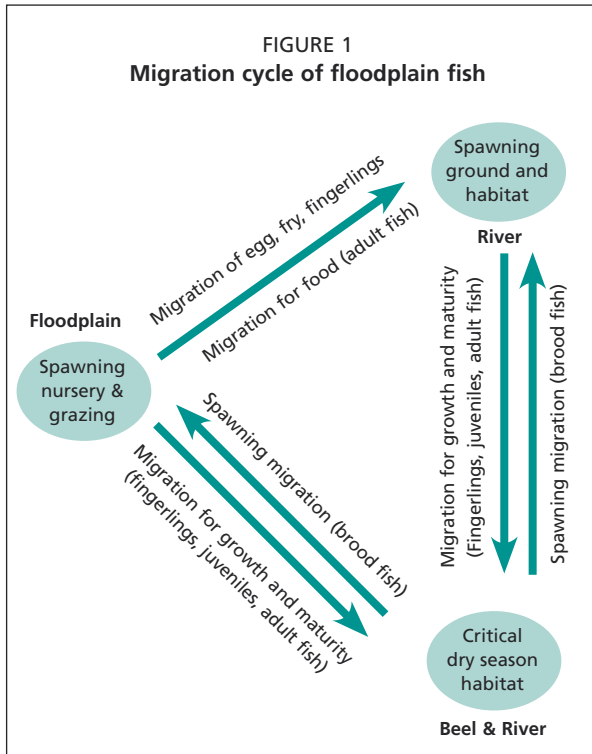
TABLE 2
Four species of major carp of Bangladesh with key biological and aquaculture characteristics

Major carp species	Key biological and aquaculture characteristics
 Catla: <i>Catla catla</i>	Age of maturity: 3–5 years Trophic level: Surface feeder Growth potential: High Aquaculture potential: High Share in pond aquaculture: 19.9 % (2004–05) Share in Kaptai Lake: 31 % of major carp (2004–05) Share in annual Beel catch: 7 % (2004–05)
 Rui: <i>Labeo rohita</i>	Age of maturity: 2–3 years Trophic level: Column feeder Growth potential: Medium Aquaculture potential: High Share in pond aquaculture: 23.4 % (2004–05) Share in Kaptai Lake: 11.9 % of major carp (2004–05) Share in annual Beel catch: 8.2 % (2004–05)
 Mrigel: <i>Cirrhinus mrigala</i>	Age of maturity: 2–3 three years Trophic level: Column feeder Growth potential: Medium Aquaculture potential: High Share in pond aquaculture: 16.2 % (2004–05) Share in Kaptai Lake: 6.9 % of major carp (2004–05) Share in annual Beel catch: 7.3 % (2004–05)
 Kalibaush: <i>Labeo calbasu</i>	Age of maturity: 3 three years Trophic level: Column feeder Growth potential: Medium Aquaculture potential: Low Share in pond aquaculture: 0.6 % (2004–05) Share in Kaptai Lake: 50.1 % of major carps (2004–05) Share in annual Beel catch: 2.2 % (2004–05)

All of these species require similar environmental conditions and use similar spawning grounds (Tsai and Ali, 1985). Each carp species undertakes a spawning migration to reach their respective breeding grounds (Tsai and Ali 1985, 1986). The adult carp begin their spawning migration in the pre-monsoon season (March), coinciding with the gradual rise of water flow due to snow melt in the Himalayas, and the early rains and the rise in water temperatures. Spawning starts in May with the onset of southwest monsoon rains, and continues until July (Azadi, 1985; Saha and Haque, 1976; Tsai and Ali, 1985). Soon after spawning, the adults and fish larvae migrate downstream to the floodplains for feeding and remain there for 4–5 months. They passively migrate with the water current, and drift laterally onto the extensive productive floodplains (Figure 1). They then migrate back to deeper areas in the rivers and *beels* for overwintering along with the receding water during late monsoon. The fish over-winter in these habitats, escaping mortality from fishing and natural causes, and start their spawning migration in the next pre-monsoon season. Although much is known about the spawning behaviour of major carp, there is little detailed knowledge of their spawning behaviour in relation to environmental requirements.

Wild stock of major carp

Based on the differences in the spawning grounds, spawning seasons, and geographic distribution, the major carp in Bangladesh are often divided into four stocks named by the respective river system: i) Brhamaputra-Jamuna stock, ii) Upper Padma stock, iii) Upper Meghna stock, and iv) Halda stock (Azadi, 1985; Tsai and Ali, 1985). There is little information available about another stock of major carp, in Kaptai Lake.

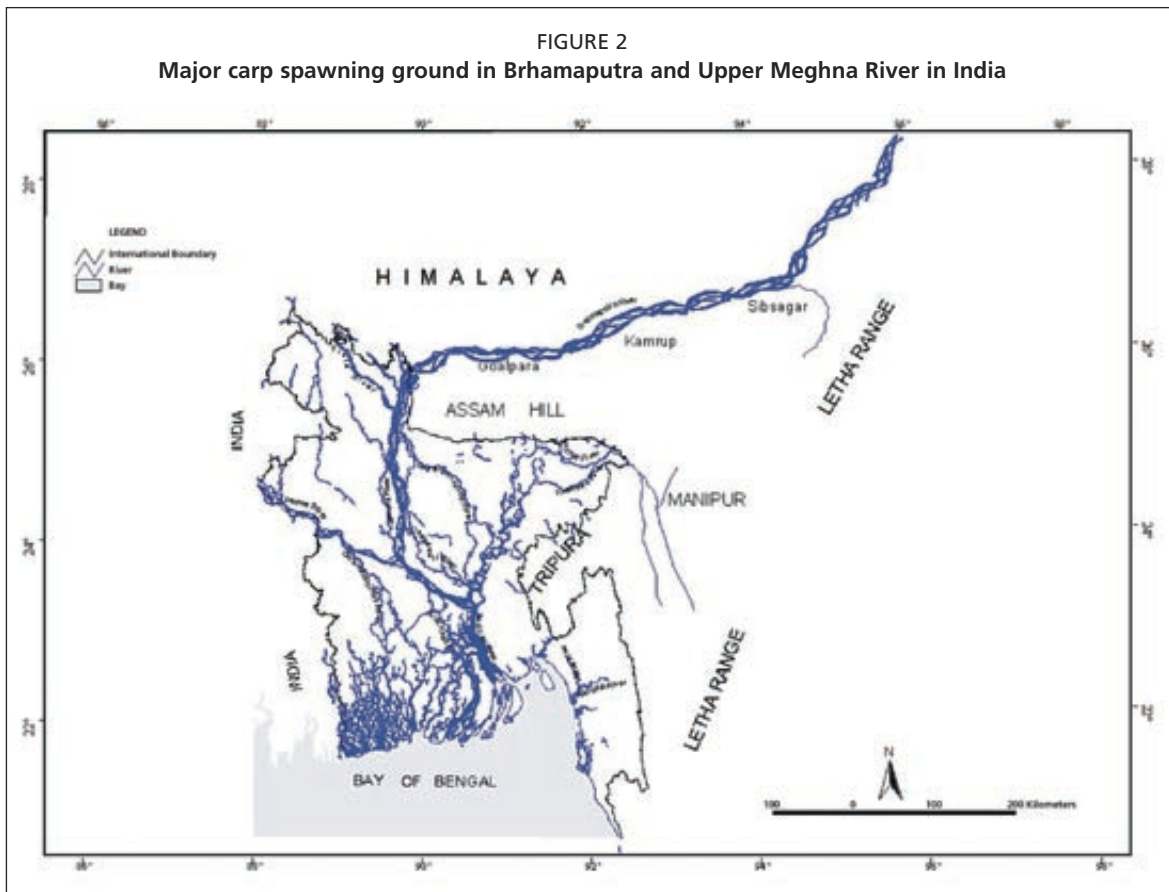


Brhamaputra-Jamuna stock

The Brhamaputra stock is the largest in Bangladesh, covering a wide range of areas and various tributaries of the Brhamaputra and Jamuna river systems (Azadi, 1985; Tsai and Ali, 1985; Tsai *et al.*, 1981). The rivers and floodplain *beel* included in this stock cover Brhmaputra, Jamuna, Old Brhmaputra, Kaliganga, Dhaleswari, Meghna (down to its confluence with the Old Brhamaputra River), lower Padma (down to its confluence with the Jamuna river), Kumar, and Arial Khan rivers and their tributaries, and canals and *beels* in the Borga, Pabna, Dhaka and Faridpur basins (Tsai and Ali, 1985).

The carp in this stock possibly do not spawn within Bangladesh, as only major carp juveniles are collected from the Brhmaputra-Jamuan river systems even in the upper reaches of the river near the Indian border (Kurigram district). The Brhamaputra-Jamuna stock travels a long distance from the lower

reaches of the rivers to their spawning grounds at the southern tributaries of the upper Brahmaputra river in the Assam Hills and Letha Range, in Assam, India (Alikhuni, 1957) (Figure 2). The major carp in this stock spawn in the wild. Major pulses of spawn are caught in May and June, with less captured in July, coinciding with the onset of the southwest monsoon with the rise of water flow, temperatures and rainfall.



The Brhamaputra stock of major carp start their spawning migration from their over-wintering habitats at the lower reaches in late February and continue until late April, coinciding with the gradual rise in water flow and temperature, and often with the start of the pre-monsoon rains. These fish perform a long, mostly longitudinal, migration to reach their spawning grounds. Soon after spawning the adults swim back along the river and laterally migrate to floodplains for feeding and growth until the late monsoon, and then they migrate to deeper pools in rivers in lower reaches as well as large perennial *beels* in the floodplains.

Upper Padma stock

This stock of major carp is found in the Padma River below the Farraka Dam and its associated tributaries, canals and *beels*. This stock occurs in the lower Meghna, Kumar, Arial Khan, and in other rivers below the confluence of the Padma and Jamuna rivers. This stock thus mixes with Brhamaputra-Jamuna stock due to close downstream connectivity among the rivers.

Similar to the Brahmaputra-Jamuan stock, no eggs from this stock are collected in the Padma River within Bangladesh, indicating that spawning occurs upstream and outside of Bangladesh. In neighboring India, the most important fry collection center in the Ganges River is upstream of Farraka Dam, where fry are collected from May to September (Jhingran, 1983). In Bangladesh, fry collection in the Padma River takes place during June, July and August, suggesting that there might be a different spawning ground of major carp in the Padma River downstream of the Farraka Dam (Tsai and Ali, 1985). Based on the time of availability of carp spawn in the Upper Padma, it is assumed that the spawning migration of major carp in the Padma River occurs from April to May/June, which is later than that of the Brhamaputra-Jamuna stock. As with the Brhamaputra-Jamuna stock, after spawning, the adults of the Padma stock move back and laterally migrate to flooded lands for feeding and growth.

Upper Meghna stock

This stock remains at the upper reaches of the Meghna River from its confluence with the Old Brhamaputra River, up to the tributaries, *beels* and *haors* in Bangladesh and India (Borak River basin). The major tributaries in the area include the Surma, Kushiya and Khoai rivers that originate in the Letha Range, as well as the Boulai River that originates in the southern slope of the Assam Hills of India. There is relatively little information on carp spawning grounds and spawn collection centers on the upper Meghna in Bangladesh.

Unlike other river systems, there are no commercial carp spawn collection centers in the Upper Meghna River basin. Spawning of this stock may take place long distances upstream in India, or the spawning may be so limited that it does not attract fry/spawn collectors. However, some authors indicate that there are spawn collection centers located at the headwaters of the Surma River in Manipur province, and some in the Tripura province in India (Jhingran, 1983).

Paul (1997) does mention some locations where local fishermen collect carp spawn from the wild, noting seven carp spawn collection points in the greater Sylhet basin: i) Juri river in the Hakaluki haor upstream from the Fenchugonj Bridge; ii) Kawani River near Daulatpur and Milonpur, the Boroia River near Shanbari bazaar, and the Baulai River near Mukshedpur in Dharampasha Upazila; iii) Baulai river near Alamduarer bank in Tahirpur upazila; iv) Surma River near Sunamgonj; v) Dhanu River near Ranichapur and Chalamati of Khaliajuri upazila; vi) Kalni River near Maruli of Derai Upazila; and vii) Khoiltajuri River near Dighirpar in Companigonj Upazila. However, these sites have not been investigated, and thus detailed information on the natural carp spawn collection and breeding grounds in the area is not available.

Halda stock

The Halda River in the southeast of Bangladesh originates from three major tributaries that come out of the Chittagong Hill tracts, namely the Dhurang, Talpari and Sareakhal. The river flows downstream and discharges into the Bay of Bengal, joining with the Karnafuli River at the south end where there are visible tidal effects. The river has meandering courses, and there are three ox-bends (Ankurdigji, Sonairchar and Urchirchar) in the southern reach of the river covering 32 km, that are reported to be the major carp spawning grounds. Three species of major carp (*C. catla*, *L. rohita* and *C. mrigala*) spawn in this tidal river every year. This is the only tidal river located very close to the coastline where major carp have been naturally spawning. This spawning ground is considered as one of the richest and oldest carp spawn fisheries, and has been meeting the demand of carp fry for pond aquaculture in the immediate area as well as much of the other parts of the country.

Other stock – Kaptai stock

This stock of major carp is limited to Kaptai Lake and its associated tributaries in the southeastern hill district of Bangladesh and constituted about 21 percent of the total landings (Hye, 1933). As with other stocks, spawning also occur here during May and June. Kaptai Lake, located in the Chittagong hill tract, is an oligotrophic lake containing a major carp stock, and the Freshwater Fisheries Research Sub-Station at Rangamati reports some carp spawning grounds in this lake. Collection of carp fry from the lake by the staff of the Research Sub-Station was noted by Azadi (1985). Possible spawning grounds in this lake included the Kassalong range (Mainimukh to Marishaya), the Barkal range (Subalong to border area), the Chengi range (Burighat to Mahalchari) and the Reinkonh range. These points are located at the headwaters of the Kaptai Lake however no detailed study on the major carp spawning is available.

MAJOR CARP FRY FISHERIES

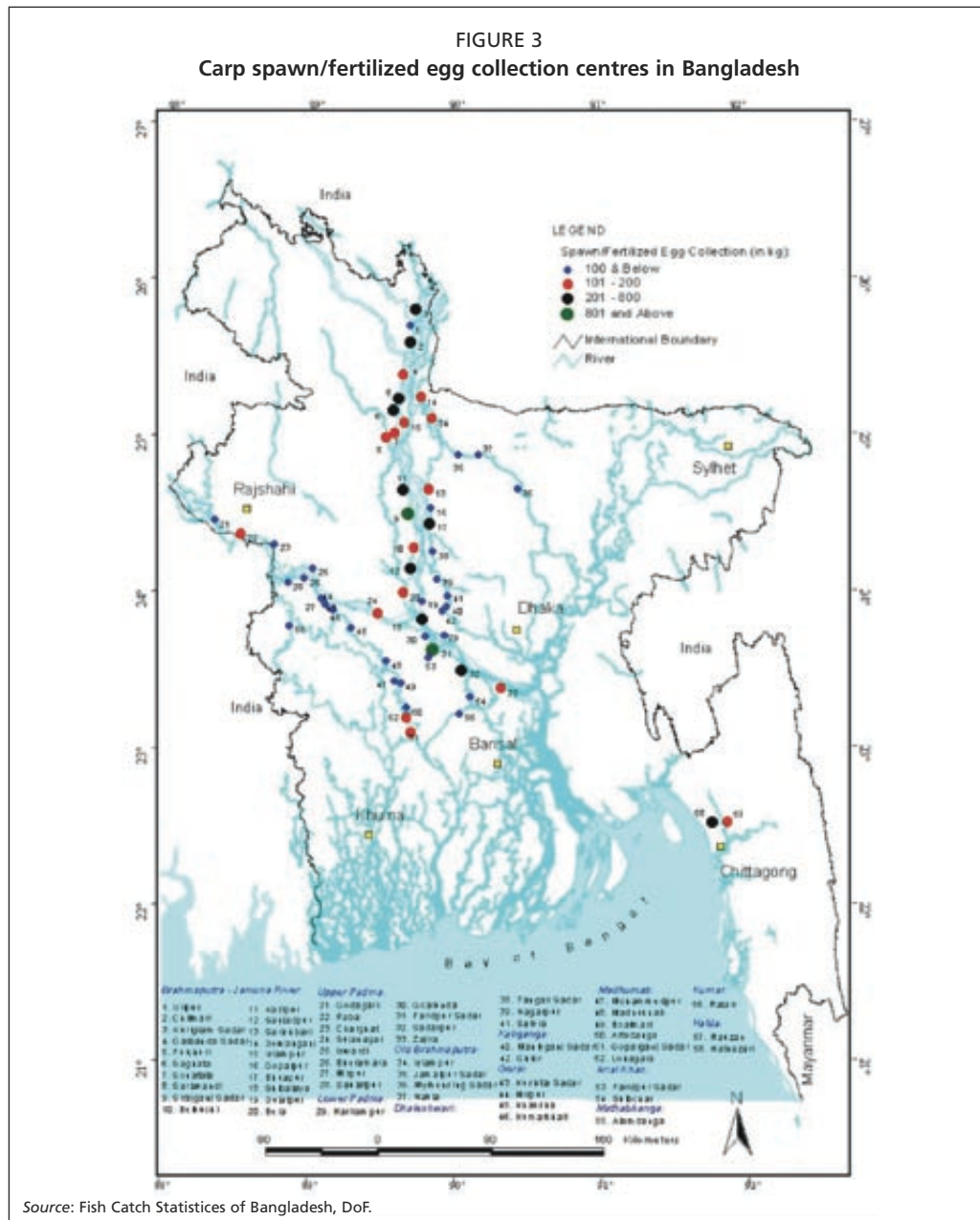
All floodplain fish species in Bangladesh spawn in the pre-monsoon to monsoon months (March–October), the exact timing depending on the climatic conditions that affect the different species. All four species of carp breed during the monsoon and rivers play a vital role in their breeding functions. Therefore, rivers not only providing habitats for the capture fishery, but also support the very important major carp grow out, spawn and fry fisheries.

The collection of major carp spawn from rivers for sale to the aquaculture industry is an old practice in Bangladesh. Therefore, information related to places and time of carp spawn collection is well known. However, detailed information of all the spawn collecting sites in the country, with quantity and quality of spawn, and with relevant socioeconomic attributes is not well documented. The only reliable or usable source of carp spawn data in the country is the Fisheries Resource Survey System (FRSS) of the Department of Fisheries (DoF).

Spawn or fry collection has been the only source of initial support for the aquaculture or the culture fishery sector in Bangladesh until artificial spawning in hatcheries started in the early 1980s.

Fry collection sites

Of the various river systems from which the carp spawn is collected, three rivers and their tributaries are particularly important. These are Ganges–Padma (southwest), Brahmaputra–Januma (north central) and Halda (southeast) river systems. It is estimated that there are over 90 spawn collecting centers or points in the country's three major river systems (Figure 3). Of the various points for spawn collecting and sales, the location in Sirajgonj on the Jamuna River is one of the most important sites.



Source: Fish Catch Statistics of Bangladesh, DoF.

In June 1994 approximately 5 million taka (US\$73 000) worth of spawn was sold or distributed for every single mile of the river fished.

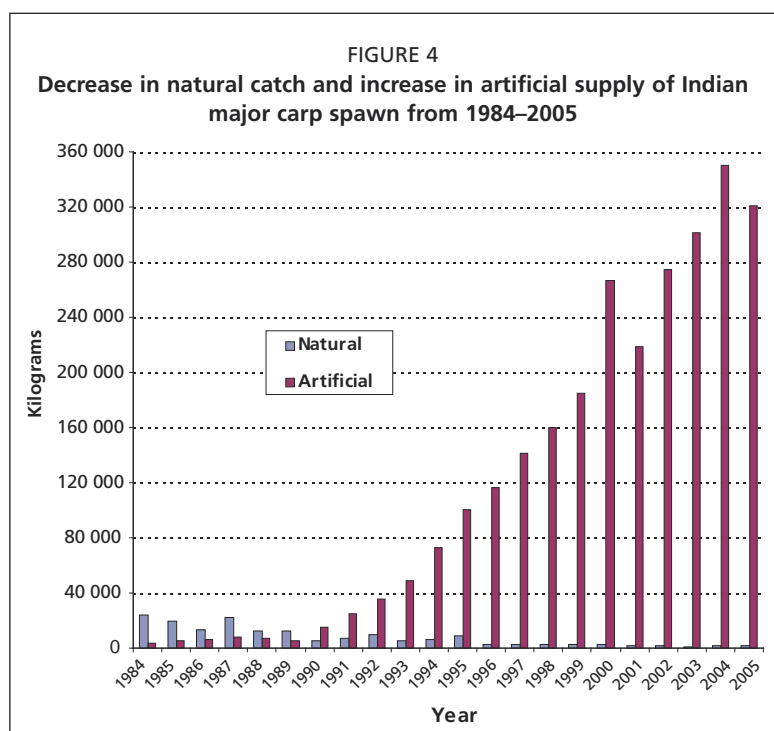
Species of carp by river systems

The major carp species in the collected spawn from the Halda River are catla (*C. catla*) (70%), the remainder being rui (*L. rohita*) and mrigel (*C. mrigala*), with catla being the fastest growing Indian major carp species. The demand for Halda spawn remains very high compared to spawn from other river sites. Tsai and Ali (1987) analysed species composition of fingerlings raised from Halda spawn stocked and found that catla comprised 81.8 percent, while rui was 9.5 percent and mrigel was 8.7 percent. The fry captured a month later had a different composition, with catla, rui and mrigel being 23.5, 32.8 and 43.2 percent, respectively. This suggests that major spawning of catla takes place earlier than other two species in the Halda River, although these three species started spawning on the same dates and in same spawning grounds. The Halda adult carp fishery is also dominated by the abundance of catla followed by rui and mrigel.

TABLE 3
Species composition of spawn (excluding Hilsa spawn) in the Lohajang River in 1994

Species	Percentage of total	Remarks
<i>Labeo rohita</i>	30.4	Major carp
<i>Cirrhinus mrigala</i>	2.9	Major carp
<i>Catla catla</i>	0.9	Major carp
<i>Colisha lalius</i>	5.8	Gourami
<i>Glossogobius giuris</i>	23.5	–
<i>Rasbora daniconius</i>	19.6	Small fish
Others	16.7	Unidentified fish

The spawn of other river systems (Ganges-Padma and Brahmaputra-Jamuna) is a mix of all species of major carps, including a small percentage of minor carps (*Labeo bata* and *Cirrhinus reba*). A study on the species composition of spawn of Brahmaputra-Jamuna stock collected from the Lohajang River (a secondary tributary of Jamuna River) found a mix of species, as shown in Table 3. Most of the spawn collected in the Lohajang River in 1994 was made of Hilsa shab (*Tenulosa ilisha*). One of the major carp species, the rui (*L. rohita*), dominated the remainder of the spawn and constituted 30.4 percent of the total catch and nearly 90 percent of the total major carp spawn. Mrigel and catla constituted a small quantity in the catch.



Trends in natural carp spawn collection

The quantity of spawn collected from river sources was previously much higher than at present (Figure 4). The average yearly catch has declined from 17 241 kilograms in the 1980s (mean of 6 years

data), to 5 194 kilograms in the 1990s (mean of 10 years data), to only 2 255 kilograms in the 2000s (mean of 6 years data).

Degradation of natural breeding habitats

Flood Control Drainage and Irrigation (FCDI) projects have altered many important fish breeding and nursery areas in Bangladesh. The infrastructure built under FCDI projects, such as embankments, sluice gates and closures, not only reduced the wetland area but also blocked and/or obstructed the fish migration routes. As a result, migration for spawning, nursery and feeding areas has been seriously impacted, resulting in a decline in the carp fishery as a whole. The Farrakka barrage caused severe damage to the Upper Padma stock, hindering both adult migration to their breeding habitats and the subsequent drift of spawn downstream. This problem of free passage is further aggravated by the shortage of water in the dry season, leaving the fish vulnerable to fishing and natural causes. The stocks of mature wild fish have seriously declined, and this affects overall fish production, especially among major carp species that require 2 to 3 years to attain sexual maturity.

Destructive fishing practices, such as the increased use of fixed gears across rivers and canals during fish migration, the complete water drainage of the wetlands in the dry season, and the use of monofilament nylon gillnets have collectively impacted the capture fishery as a whole.

Fry sources

Over the last decade there has been a major shift in demand from wild-caught major carp spawn to hatchery-produced spawn. This has mainly been due to establishment of numerous private and government hatcheries and nurseries. The production capacity, especially that of the private facilities, has increased many fold, and their services and communications have also improved, thus providing a very attractive alternative to wild-caught spawn. Furthermore, by purchasing hatchery-raised fry, the customer is assured of getting the desired species, whereas with wild-caught spawn there is often the risk of getting spawn that includes several fish species. However, many hatchery operators use poor quality broodstock, producing inferior quality fry, thus creating a negative image among potential customers.

Spawn fishing gears

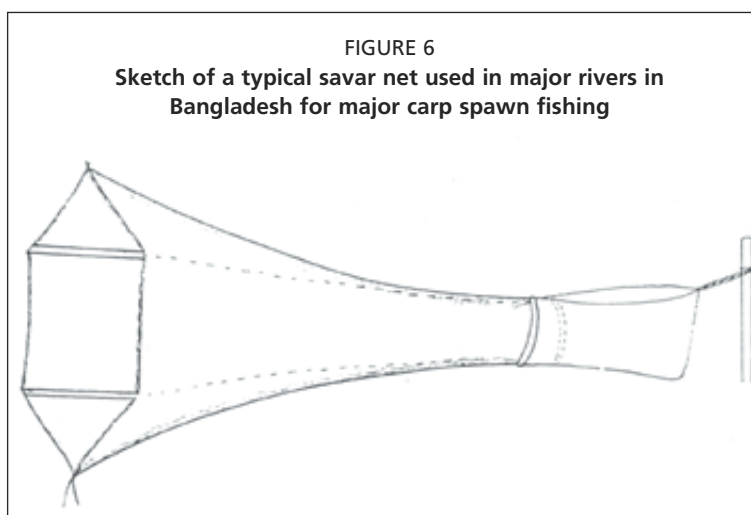
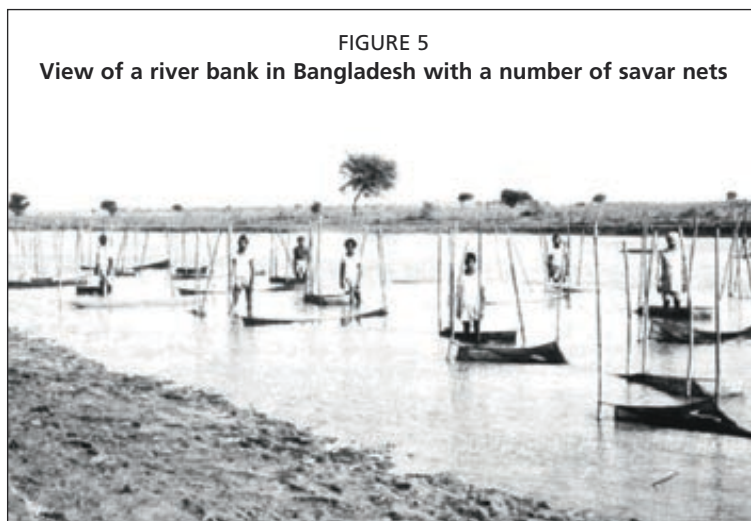
The major carp spawn fishing gear that has traditionally been used in the two major river systems (Ganges-Padma and Bhrhamaputra-Jamuna) is a funnel shaped fixed net, popularly called a “savar net”. This is a type of set bag net specially designed to fix the net at the shallow, gently sloping shoreline of the rivers, where the depth of water is negotiable without any aid.

The savar net is usually small, with a collection pocket at the tail end (Figures 5 and 6). The net is made of a fine mesh that traps tiny eggs or spawn that drift with the water flow during the monsoon months. A water flow in the range of 20–60 cm/sec. is desirable for spawn trapping (Kumar, 1992). The accumulated spawn are collected and held in water for sale and transportation. These nets are locally made and easily available, costing approximately US\$10 each.

Natural fish spawn collection method

The savar spawn collection nets are placed in several rows near the shore, facing the current, at intervals of 2–8 m, and each row may have between 3–15 nets. The front extensions of the adjacent nets are tied together to the same bamboo pole, the poles having been set in the river at the beginning of the fishing season to mark the area of each savar site. The upper edge of the tail bag is kept about 4–5 cm above the water surface to prevent the escape of spawn.

When the river water rises to a level favorable for spawn collection, a few test nets are set. As soon as the desired spawns are spotted in the test nets, all the nets are set rapidly in the river, and spawn collection begins in earnest. A collector walks from



one net to another at regular intervals to scoop up spawn from the tail bag and place it in an earthen or aluminum pot known as *patil* or *handi* (Figure 7). The spawn are subsequently sieved through a screen box and kept in *hapas* nets fixed near the spawn collecting sites to await sale.



Boats

Locally made boats of various sizes and shapes, mechanized and non-mechanized, are used for spawn collecting and transport. The most commonly used boat is small and normally carries 1–2 fishers while larger mechanized boats may carry up to 3 fishers and are usually preferred as the collected spawn can be transported quickly to the sale sites.

Handling and transportation of spawn

Usually a spawn collector operates more than one net, depending on the suitability of the sites and extent of spawn availability. Depending on silt load, water depth and spawn pulses, the operators remove, clean and reattach the nets as needed. During strong spawn pulses the spawn is scooped from the net traps every 15 to 30 minutes. The collected spawn is then transferred to aluminum or clay containers partly filled with water (Figure 8). The spawn is then sieved through mosquito netting, to separate major carp spawn from debris and larger fish. The spawn is then conditioned in either *hapas* or in small earthen ponds before transportation.

The spawn collected from rivers is generally a mixture of spawn of major carps, minor carps, and other fishes. The operators often try to segregate the major carp spawn from the spawn and fry of other fishes either before or after conditioning.

FEEDING OF CARP SPAWN

Nursery rearing of fish seed generally has two distinct phases: (i) rearing of post-larvae to fry and (ii) rearing of fry to fingerling. In the earlier developmental stage the fry are dependent on natural live food from the pond itself, which can be enhanced through pond fertilization (mustard oil cake) and manuring (caw dung). As the post-larvae develop, their diet changes from microorganisms such as protozoa, to larger prey items such as rotifers. At the post-larvae stage, due to their feeding habit and mouth size, the fish will not take any artificial feed even if it is supplied. Nursery operators in Bangladesh do not normally use wild-caught food. Instead, they produce live food in the nursery ponds and, as the fry grow bigger, they start supplying supplementary feed. A typical feeding schedule for carp post larvae/fry is given in Table 4.

Once the fry are released into the nursery ponds, both hatchery-produced seed and wild seed receive the same treatment described above. Within 3–5 days the natural food produced in the nursery pond is usually consumed and supplementary feeding is needed. The feed is usually prepared at the farm, with attention being given to maintaining a good nutritional balance, and sometimes the food is fortified with vitamins and minerals. Wheat or molasses are sometimes used as binders. Seed growers use only mustard oil cake mixed in water and the solution is sprayed over the water. Subsequently rice bran is mixed with mustard oil cake at a ratio of 1:1. At the fingerling stage, oil cake, rice bran or wheat bran is used, along with other protein sources like fishmeal



TABLE 4
Feeding schedule of carp post larvae/fry for the first 50 days after stocking

Days after stocking	Feed per day
1–5	2 x weight of stocked biomass
6–10	3 x weight of stocked biomass
11–15	4 x weight of stocked biomass
16–25	40–45 g/decimal ¹ /day
26–35	80–100 g/decimal/day
36–50	200 g/decimal/day

¹ 100 decimals = 1 acre; 2.46 acres = 1 hectare.

or blood from cattle. At this stage the feed is normally granular or in pellets. In carp nurseries the feed is normally applied at around 10 a.m. If feed is applied twice a day, the second feeding is in mid-afternoon, with equal amounts given at each feeding. Some carp nursery farmers use artificial feeds for catfish and shrimp in order to achieve faster growth.

AQUACULTURE DEPENDENCE ON THE WILD FISH SEED

Over the last 15 years there has been a marked decrease in dependence on wild seed of major carp for aquaculture due to increasing capacity for producing spawn at private and government hatcheries in Bangladesh (see Figure 4). In 1965, induced spawning of major carps was first successfully demonstrated at the Freshwater Fisheries Research Center (FFRC) and in the early 1980s commercial hatchery production of carp fry was initiated at the FFRC. Since then, a rapid proliferation of hatchery spawn production has occurred in both the public and private sectors.

The Fish Seed Multiplication Farms (FSMFs) of the DoF (Department of Fisheries), and some fisheries research and training centers of the DoF, also established large hatcheries in the 1980s and started mass production of major carp spawn, and that of various exotic carps. The successful operations of the government hatcheries created a large market for the induced spawn, and a growing demand for hatchery-produced spawn. The availability of quality spawn for selected species positively impacted the rapid expansion of pond aquaculture all over the country.

However, the growth of the aquaculture industry was so rapid that the government hatcheries could not meet demand, and space was created for the growth of private sector hatcheries. Private entrepreneurs developed innovations in hatchery systems, in their design (e.g. circular, funnel or bottle-type incubators), as well as in the techniques for broodstock and nursery rearing. The BFRSS data shows that in 1985 there were only 69 private hatcheries that collectively produced 3 952 kilograms of carp spawn with an average production of 57 kilograms per hatchery. By 2005, the number of private hatcheries had increased to 731 (Table 5) and they produced 315 892 kilograms of carp spawn, which comprised over 98 percent of the total annual carp spawn production of Bangladesh.

ADVERSE IMPACT OF SAVAR FISHING

The adverse impacts of savar fishing for carp spawn have been summarized as:

- Reducing the natural recruitment potential of carp (also to some extent, that of other species) and thereby gradually diminishing the natural stock.
- Reducing the shallow nursery and rearing areas in the river basin due to operation of savar fishing, thus negatively impacting natural productivity.
- Reducing the natural gene pool due to indiscriminate savar fishing.
- Affecting the natural productivity of carps in the wild due to mishandling of spawn fishery operations by inexperienced net operators, which may cause mass mortality of spawn.
- Negatively affecting overall capture fisheries production in the wild as a result of thousands of spawn of other fishes being damaged during the process of catching major carp spawn.

RECOMMENDATIONS

- Identify all the major carp natural breeding grounds both inside and outside Bangladesh through scientific investigations, and delineate them for future protection and enhancement of habitats.
- Obtain data on each natural major carp spawn collection center, investigate and update and map their biophysical and socioeconomic attributes (for example where they harvest and when, types and numbers of nets, quantity and quality

TABLE 5
Growth in number and productivity of private and government hatcheries, 1985–2005

Year	Private hatcheries					Government hatcheries				
	No. of hatcheries	Spawn production (kg)	Average spawn production kg/hatchery	Growth in spawn production since 1985 (%)	Growth in the number of hatcheries since 1985 (%)	No. of hatcheries	Spawn production (kg)	Average spawn production kg/hatchery	Growth in spawn production since 1985 (%)	Growth in the number of hatcheries since 1985 (%)
1985	69	3 952	57			78	1 010	13		
1986	117	4 911	42	24	70	80	1 376	17	36	3
1987	214	6 880	32	74	210	82	1 459	18	44	5
1988	162	5 697	35	44	135	82	1 152	14	14	5
1989	526	4 315	8	9	662	84	1 348	16	33	8
1990	204	13 014	64	229	196	89	1 758	20	74	14
1991	218	22 171	102	461	216	89	2 512	28	149	14
1992	222	33 070	149	737	222	85	2 781	33	175	9
1993	256	45 701	179	1 056	271	102	3 263	32	223	31
1994	439	69 356	158	1 655	536	102	3 180	31	215	31
1995	533	97 205	182	2 360	672	102	3 272	32	224	31
1996	616	112 596	183	2 749	793	102	3 616	35	258	31
1997	473	137 042	290	3 368	586	101	3 888	38	285	29
1998	613	162 781	266	4 019	788	103	4 014	39	297	32
1999	591	180 551	306	4 469	757	112	4 112	37	307	44
2000	629	262 859	418	6 551	812	112	3 994	36	295	44
2001	667	214 682	322	5 332	867	112	3 663	33	263	44
2002	671	271 277	404	6 764	872	112	3 229	29	220	44
2003	696	297 781	428	7 435	909	112	3 902	35	286	44
2004	756	345 227	457	8 636	996	112	4 802	43	375	44
2005	731	315 892	432	7 893	959	112	5 128	46	408	44
Total		2 606 960					63 459			

- of spawn caught, how many people are engaged, who they are, what do they do, income and expenditure in spawn fishing, marketing and transportation).
- Undertake research to improve the spawn collection systems and techniques to reduce anthropogenic (human-induced) mortality and improve rearing and transportation systems.
 - Identify the current barriers and constraints to the carp spawn fishery in the wild, especially regarding overwintering and migration of broodstock, morphological aspects of habitats (especially in the Halda River) in the context of water control structures, and suggest measures to overcome these barriers.
 - Conduct socioeconomic studies of the people engaged in major spawn fishing in the wild and suggest alternative livelihood options to reduce pressure on this fragile and sensitive major carp spawn fishery.
 - Ensure that existing sluice gates/water control regulators are operated in a manner that would facilitate fish and larval migration from rivers to floodplains and vice versa.
 - Establish closed areas and seasons to allow major carp broods to migrate to their spawning grounds and spawn successfully.
 - Declare and delineate carp sanctuaries in the wild, as has been established in the for the *hilsa* (river Shad) fishery in the Meghna River and its tributaries.
 - Reduce and restrict the dependence of aquaculture on wild spawn through the improvement of hatchery production systems.
 - Reexamine and update fisheries rules relating to spawn fishing from the wild, in order to facilitate natural replenishment of wild stock of fish including major carps.

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Capture-based aquaculture of the wild European eel (*Anguilla anguilla*)

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SUMMARY

The European eel, *Anguilla anguilla*, has a long and complex biological cycle. Its area of distribution covers Europe, North Africa and Iceland. All its continental life stages are exploited by fishing, and human activities have dramatically reduced its habitat.

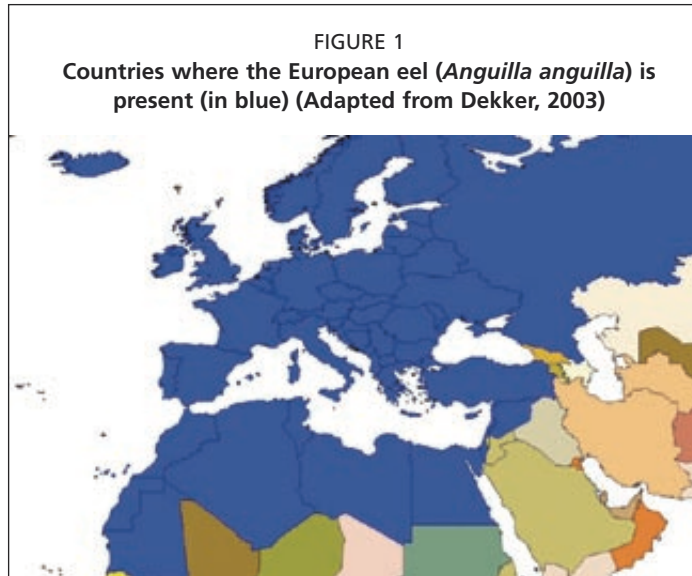
Farming of the European eel started some 25 years ago, and currently supplies approximately 45 000 tonnes/year which is >80 percent of the world's consumption of the species. Farming techniques are now reliable, in both Europe and Asia, where most of the eels are produced. The industry is however still totally dependant on wild-caught juveniles (i.e. glass eel) caught by fishers during their migration from the sea up freshwater rivers and streams. The main harvest is recorded in the river estuaries along the Atlantic coast.

Reproduction of *Anguilla anguilla* has not yet been achieved in captivity. The fishing for glass eel, along with environmental pollution and other human impacts, have all contributed to a significant decline in eel numbers over the last 25–30 years. Total volume of glass eels collected on an annual basis is around 150 tonnes which satisfies the current aquaculture needs of approximately 100 tonnes/year with the excess going to human consumption in Spain. Many people are involved in the eel collection, transportation and distribution, from glass eel fishers to the eel farmer and processor.

Aquaculture production presently satisfies the market demand, and no major new development is expected in the coming years. The feed sources for eel aquaculture are multiple and reliable. The only weak link in the chain is the supply of the wild-caught juvenile glass eels, which poses a real problem, as the eel is now considered “outside the safe biological limits and the current fisheries are not sustainable”.

In order to restore the eel population, the European Union (EU) has proposed a management plan which includes reducing the current harvest levels for all life stages and improving the carrying capacity of continental waters. The long term objective is to reach an escape level equal to at least 40 percent of the silver eel biomass produced in an

undisturbed environment. This also includes some export restrictions of the glass eel to Asia or generally outside Europe in order to retain the wild seed in the region as much as possible for stocking and farming activities.



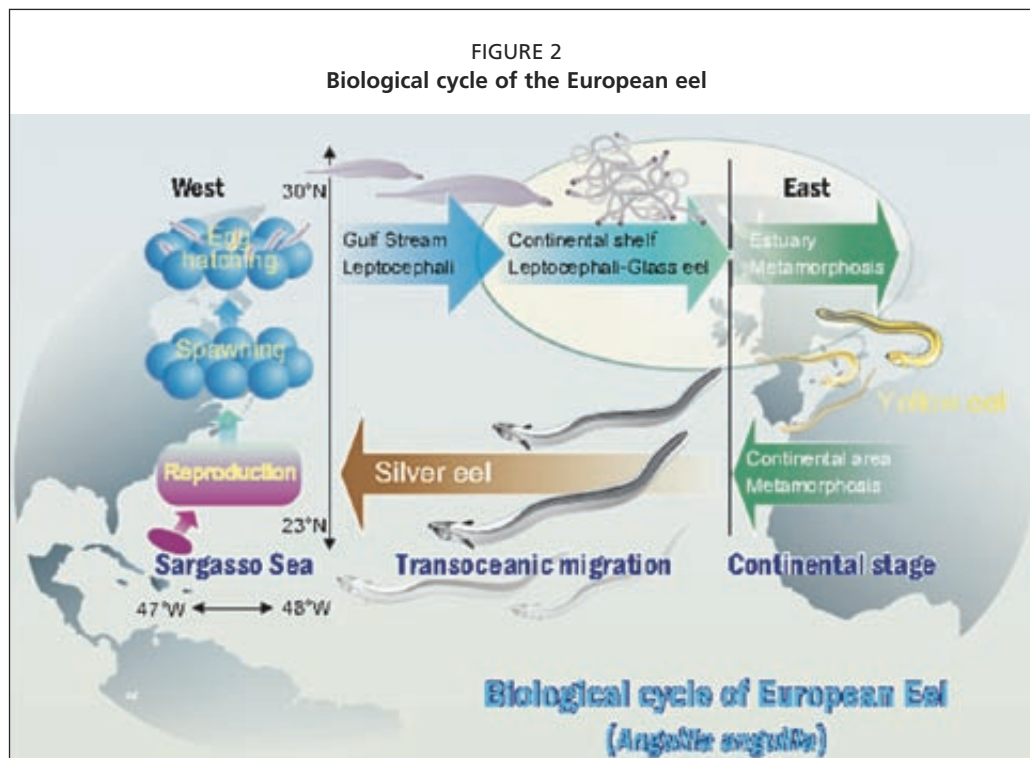
DESCRIPTION OF THE SPECIES AND ITS USE IN AQUACULTURE

Biological outlines

The European eel (*Anguilla anguilla*) occurs from Mauritania to the Arctic Circle and the Mediterranean, and is an amphihaline and catadromous species with a complex biological life cycle, many aspects of which are still poorly understood or undocumented (Figures 1 and 2). For example, reproduction has never been observed and no eggs or spawning adults have been collected in the supposed spawning area which has been identified by Schmidt (1925) in the Sargasso Sea (Nilo and Fortin, 2001).

The taxonomic status of the species is still very vague and some hybridization between European (*Anguilla anguilla*) and American (*Anguilla rostrata*) eels has been observed (Boëtius 1980; Avise *et al.*, 1986; 1990). Regarded as a panmictic species, some recent papers hypothesise that the European eel is formed by 3 genetically differentiated sub-populations (Wirth and Bernatchez, 2001; 2003).

However, recent work shows a strong intra-genetic variability that exceeds the inter-genetic diversity among samples collected from various European stocks (Dannewitz



et al., 2005). This seems to indicate that the panmixia hypothesis is still valid and the results obtained by Wirth and Bernatchez (2001) could be an artefact linked to a meta-population structure of the species (Maes *et al.*, 2006; Pujolar, Maes and Volkaert., 2006).

Even in the absence of genetic structuring, there are physical, biological (particularly the diversity in the oceanic migration paths and intensity of estuarine recruitments) and socio-economic characteristics that make it possible to distinguish three geographical groups which produce silver eel populations with different mean age and growth attributes. The first is the “northern group” (North Sea and Baltic Sea) with low glass eel recruitment, producing silver eel with a slow growth rate that migrate towards the Sargasso Sea at a high mean age (Tesch, 1977). The exploitation of eels is focused primarily on the silver and yellow eel stages.

The second group is found in the Atlantic area from the British Islands to Portugal and is characterized by larger recruitment into the catchment areas. The biological cycles are of variable duration, from 5 to 15 years, and the sex ratio varies according to the physical and trophic characteristics of the habitat (Acou *et al.*, 2004; Acou, 2006). The fishery mainly targets the glass eel stage, but some yellow and silver eel fisheries are well developed on certain rivers (e.g. Somme, Loire, Gironde) and along the littoral marshes of the Atlantic coast (Prouzet, 2002; 2003b). The third group, referred to as the “Mediterranean group”, is characterized by sparse glass eel recruitment. This group is more abundant than the one in the northern area, as demonstrated by the glass eel fisheries occurring in some Italian estuaries (Ciccotti, 2005). The biological cycles are often short and the stock is largely confined to coastal lagoons, particularly along the northern Africa and the French Mediterranean coasts. Exploitation is focused primarily on yellow and silver eels.

Fishing exploitation of the species

Eel is exploited at all its development stages and in various ecosystems (marine, brackish and freshwater). Fishing intensity on the different biological stages is highly variable according to the catchment areas and the geographical “groups” mentioned above. The exploitation of the glass eel ranges from 0 percent (e.g. in the Mediterranean Sea where fishing is prohibited in many river basins) to over 90 percent (Anonymous, 2002). In 2004, Dekker reviewed the fishing impact on the eel population and particularly on the glass eel stage indicating that the exploitation has reduced the abundance of the glass eel arriving at the mouth of the rivers observed by 85 percent (Dekker, 2004). However, studies conducted on several French rivers (mainly the Adour and Loire rivers) indicate that this level of impact is not usual. The estimated rate of exploitation is not higher than 15 percent (Bouvet, Prouzet and Bru, 2006) (Table 1). The first estimates collected on the Loire River on daily exploitation using push sieves indicate that the catch is lower than 30 percent (Prouzet *et al.*, 2007). Considering that the glass eel is not exploited on many small rivers of the Atlantic coast and in many catchments located on the border of the Mediterranean, it is more realistic to consider that the global exploitation

TABLE 1
Estimates of the seasonal biomass of glass eel migrating upstream through the Adour estuary and mean rates of exploitation estimated during the recent fishing season (1998–2005)

Fishing seasons	Seasonal biomass (tonnes)	Professional catches (kg)	Estimated rate of exploitation (%)
1998–1999	40.0	1 655	4.1
1999–2000	127.7	4 579	3.6
2000–2001	29.8	1 446	4.9
2001–2002	40.6	770	1.9
2002–2003	3.5	388	11.1
2003–2004	14.8	1 093	7.4
2004–2005	43.1	1 398	3.2

FIGURE 3
Typical glass eels caught in estuaries



rate is less than 50 percent. On the Adour River, which is free of dams in its estuary, surveys were carried out on the abundance of glass eel runs during the 1999–2000 fishing season, the best fishing year of the last decade (Prouzet, 2002; Lissardy *et al.*, 2004). These studies showed that the total rate of exploitation by the push sieve fishery was 6.8 percent in the estuary, with a value lower than 6 percent one day out of two (Bru, Lejeune and Prouzet, 2004).

For yellow eel, the data show a large fluctuation of the exploitation rate according to the hydrological parameters. For example, the exploitation rate on the IJsselmeer

Lake in Holland during the period 1989–1996 was estimated at 85 percent of all males and practically 100 percent of the females (Dekker, 2000). On the west coast of Sweden the escape of silver eel is estimated at 15 percent of the virgin stock (Svedäng, 1999). At Grandlieu Lake in France the exploitation rate is estimated at 45–50 percent (Adam, 1997). This exploitation in many French rivers (e.g. Adour, Garonne and Dordogne rivers) is decreasing substantially due to the decline of the resource in many areas, but also due to the low interest among the young professional fishermen in this type of fisheries (Lissardy *et al.*, 2004; Anonymous, 2004).

The fishing effort on the silver eels is also highly variable. There is no fishing along the French Atlantic coast (except for the Loire basin) and many rivers, but this is not the case in the Mediterranean where both the silver and yellow eels are targeted (Farrugio, Peyrille and Cabos, 2006; Melia *et al.*, 2006; Prouzet and Nielsen, 2003). On the Loire River, Feunteun and Boisneau estimate an escape of between 80–90 percent from the professional fisheries (Anonymous, 2003). On the Irish Erne and Shannon rivers the escape level is on average higher than 60 percent, while less in the Baltic area where it is estimated at around 60 percent (Matthews *et al.*, 200; McCarthy and Cullen, 2000; Moriarty, 1997).

Biological stages harvested

Yellow and silver eels are generally used for human consumption as is the glass eel in Spain and in the southwestern part of France. Glass eels, elvers and, more rarely, small yellow eels, are used for aquaculture and restocking. Glass eels are the most commonly used for aquaculture purposes for several reasons (Figure 3):

- almost 100 percent of glass eels accept the initial food offered;
- they are easier to wean on artificial food;
- they have been collected for direct consumption for many decades, and the fishing industry was able to provide a good supply when aquaculture activity started;
- they are easy to transport; and
- compared to elvers they carry fewer pathogens, parasites, viruses or bacteria.

Eels easily adapt to artificial conditions, as long as stress is avoided and glass eels only need a couple of days to get used to the artificial rearing conditions and will not attempt to escape as long as the conditions remain optimum. Food is offered to the newly introduced glass eels when the water temperature reaches 18–20 °C. The main types of food used at this early feeding stage are red worms (*Tubifex tubifex*) and cod roe (or crunched mussel) in Asian and European farms, respectively. Most of the glass

eels quickly accept this food. Transition to artificial feed (i.e. paste and/or pellets) is progressive, gradually replacing the natural food with a nutritionally rich dry/artificial diet. Elvers are more difficult to wean onto artificial food, even when natural food is used to stimulate their appetite. An artificial feed with a pasty consistence is usually better accepted than pellets by wild-caught fingerlings. As only a few farmers currently base their production on elvers, the rest of this paper will deal exclusively with glass eel farming.

Difficulties in obtaining juveniles in controlled conditions

In contrast to the Japanese eel, *Anguilla japonica*, where the first glass eels were obtained in the laboratory in 2001 the success in artificial maturation of the European eel *Anguilla anguilla* has been limited until very recently (Tanaka *et al.*, 2003). The first recorded hatched larvae were described in 1983 with the prolarvae surviving only 3.5 days (Bezdenzhnykh *et al.*, 1983). In the EU “Reproduction of Eel I” project implemented from 2001 to 2003 several prolarvae hatched and survived for 2.5 days (Pedersen, 2003; 2004), while in the second phase of the same project (Reproduction of Eel II, 2005–2006), Tomkiewicz succeeded in hatching eggs from 18 female eels (personal communication). The number of hatched prolarvae from each female ranged from one to several thousands with the longest living prolarvae dying after 5 days. At this time the mouth was not open, indicating that the prolarvae probably died as a result of poor egg quality rather than from lack of food. These projects have shown how to produce European eel prolarvae and the next step is to produce higher quality eggs and to identify a suitable prolarvae feed. As a consequence of such technical difficulties, all the current production of glass eel comes from natural runs, primarily from the central colonization area, i.e. Bay of Biscay, south of the British Islands and from the Iberian Peninsula.

Farming techniques – a brief overview

Two rather different eel rearing techniques are in use: 1) the European intensive and 2) the Asian semi-intensive farming systems. A third farming technique also exists, used mainly in northern Italy and based on extensive farming in coastal brackish waters (known as “vallicoltura”), but this technique is hardly active any longer and is not addressed further in this paper (Ciccotti, 2005)¹.

European intensive farming

This technique was developed to save on energy and wastewater costs and is mainly used in northern European countries (Figure 4). The eels are reared at very high densities (up to 120 kg eels/m³ of water) in indoor tanks with a strong water flow to provide the necessary oxygen and removal of waste products, such as ammonia, faecal matters, carbon dioxide and food remnants. The effluent is recycled in a specially designed unit. The water is unfit for a direct return to the culture tanks and is restored to proper physical and chemical standards, enabling the farmers to reuse the same water. Only 5–8 percent of the total farming water volume is renewed daily to avoid the build-up of toxic substances such as nitrates. A production unit with an annual output of 100 tonnes will have a daily renewal volume of approximately 60 m³. This highly sophisticated farming technique saves considerable water and energy, but it requires a highly trained and educated team of experts to run the facility. Furthermore, it requires a high investment and the overall farming risks are high as all the tanks are

¹ After Ciccotti, 2005: “Up to the mid-1990s, Italy was the leading country in eel aquaculture, covering half of total European production, but today the Italian productive capacity and the market seem both to have reduced to about 1 500 tonnes per year. Currently, only a very small quota of the production comes from the extensive culture in the northern Adriatic (Valli) and in other coastal lagoons.”



interconnected. Most operations are automatic (e.g. feeding, grading, water parameter controls, cleaning) to save manpower. In fact, only 1.5 employees are needed for an annual production of 100 tonnes.

Asian semi-intensive farming

As more than 50 percent of all European eelers collected since 1986 are farmed in Asia a brief description of the culture system is described below (Figure 4). Culture is usually carried out in still water ponds at considerably lower densities or a maximum of 20 kg/m². Surface aerators provide the necessary oxygen and create a current which concentrates the sediment in the centre of the ponds. Water flushing, carried out twice daily, removes approximately 1/3 of the water volume and aids the removal of unwanted wastes and sediments. The waste water is usually discharged in a nearby stream. These farms occupy large areas and are located near freshwater streams as they require large volumes of water (approximately 4 000 m³ water/day/100 tonnes annual production). The culture ponds have a simple design usually separated by the water discharge channels. Most farm operations are conducted manually (feeding, grading, cleaning, etc.) and

approximately 20–30 persons are employed for each 100 tonnes produced. Heating of the water during the cold winter months is carried out using a coal boiler. These farms have a very low technical level, poor sanitary monitoring, and do not require highly educated staff to operate and manage the system.

The main problems in eel farming are the following: 1) preventing escapes; 2) the significant percentage of fish refusing the artificial feeds; 3) disease problems; 4) high production costs; and 5) the slow growth in intensive farming systems once the fish has reached an average body weight of 150 grams.

DESCRIPTION OF THE FISHING ACTIVITY

Exploitation at all biological stages in various ecosystems

As mentioned above, eels colonize various ecosystems spreading from Mauritania up to the Arctic Circle. They are found in shallow coastal waters and are able to thrive in salt water for all or most of their development phase. Eels are also found in continental freshwater lakes and ponds of various depths. They colonize the estuarine part of rivers, freshwater swamps and the salt marshes in the Atlantic coast or the coastal lagoons of the Mediterranean. In these different ecosystems, the different biological stages are exploited using a large variety of fishing gear. Glass eels or elvers are caught off the coast or in the lower sections of rivers.

Nearly all the juveniles for Europe come from fishing activities along the Atlantic coast and the English Channel. In the Mediterranean, the catch of glass eel is not allowed on the French coast, but does occur in the estuaries of some Italian rivers such as the Arno and the Ombrone in Tuscany, the Tiber and the Garigliano in Lazio and the Volturno and Sele in Campania (Ciccotti, 2005). Harvest also occurs in Spain, e.g. in the delta of the Ebro River (Diaz and Castellanos, 2005). In Scandinavia, capture of glass eel is prohibited (Pedersen, 2005).

Fishing gear used

A variety of gear has been used to catch eel juveniles (e.g. dip net, scoop net, fyke net with a fine mesh – 1 mm²), but these can be grouped in gear used by hand and gear pushed by a boat. There is an important difference in the efficiency between the two fishing techniques. In fact the catch amount is generally linked to the water volume filtered by the gear which tends to be much larger with a push sieve than with a hand sieve (also known as scoop net). Both techniques are used in France and Spain. In Portugal, on the Minho River, a special gear is used called the “tela” (Figure 5) (Coimbra *et al.*, 2005).

The sieves used are generally circular with a diameter around 1.20 m often fixed pole ranging between 3–10 m in length. In France non-commercial fishers are permitted to collect glass eels as long as the catch per day is 500 g. The width of the sieve is restricted to 0.5 m, corresponding to a filtration surface of around 0.19 m². However, in some French estuaries such as Gironde, Charente or Seudre different gear and respective dimensions are allowed as indicated in Table 2 (Figure 6). A comprehensive review on the characteristics of the fishing gear used to catch glass eels is given by Dekker (2002).

The gear describe above is usually used in the small-scale professional fisheries, which mainly occur in southern Europe (France, Spain, Portugal and Italy). An eel fishery also exists in Morocco, but it is prohibited in Algeria and Tunisia and along the Mediterranean coast of France. In the 1990s the fishery was authorized in Ireland, England and Wales (Knights, 2002; Poole and McCarthy, 2005). The boats used are generally less than 7 m in length. The investment in one such boat and the necessary fishing gear usually ranges between €20 000–30 000 (approximately US\$31 500–47 300). The investment is higher for fishing boats operating in large estuaries and in coastal waters. In France, the sale of eel fishery products by non-commercial fishers is forbidden while in the Spanish Basque region this fishery is considered non-commercial and the sale of eel by non-commercial fishers is allowed (Diaz and Castellanos, 2005).

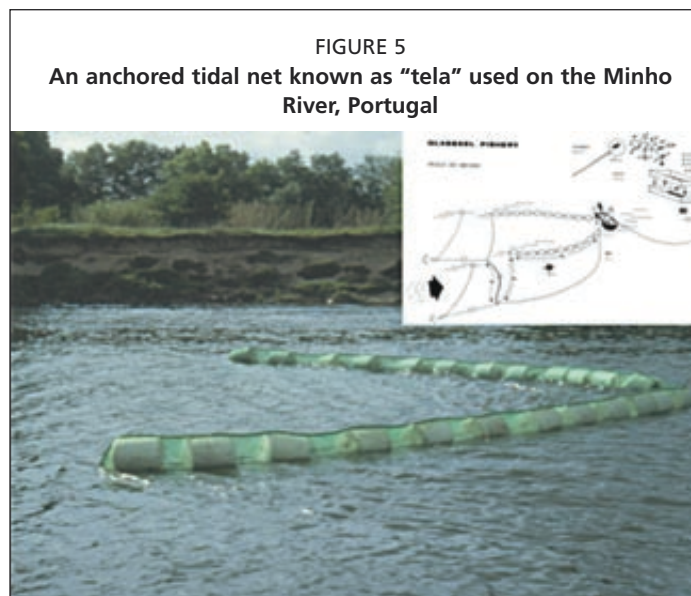


TABLE 2
Size and dimensions of the fishing gears used in France

Type of fishing gear	Shape	Surface of water filtration
Pushed net	Circular	2.26 m ²
Large Pushed net “Pibalour”	Rectangular	8–14 m ²
Pushed net	Squared	2.88 m ²
Pushed net	Rectangular	3.60–4.32 m ²
Handled scoop net	Oval	≈0.8 m ²

Source: Modified from Castelnaud *et al.*, 2005.



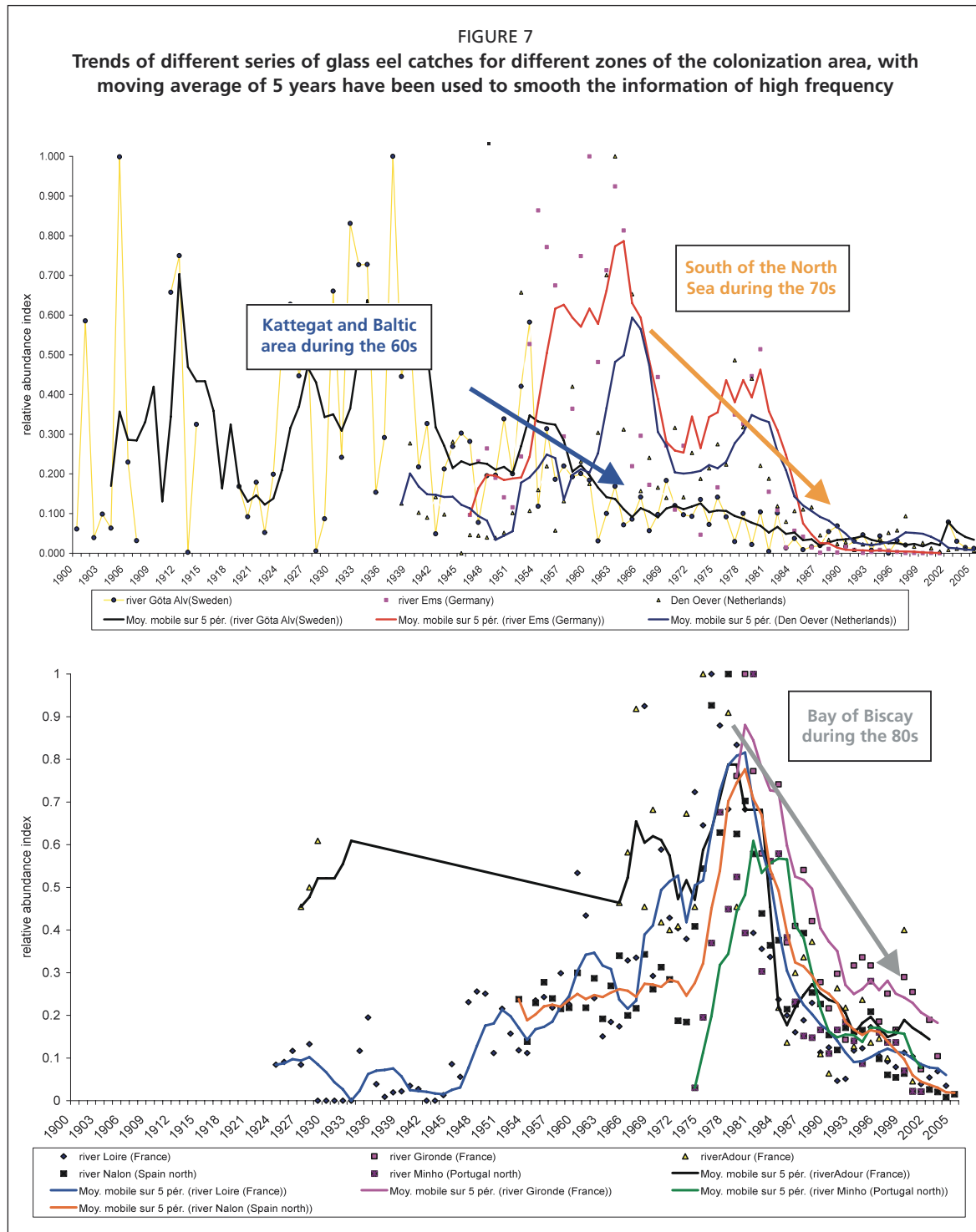
Fishing statistics and stocking effort

The most accurate series of fishery statistics for the glass eel catch comes from the joint Working Group of the International Council for the Exploration of the Sea and the European Inland Fishery Advisory Committee (ICES/EIFAC) on eel (Anonymous, 2006). The data provided by the Working Group indicates that in 2004 five countries (i.e. France, Ireland, Spain, Portugal and the United Kingdom) declared a total production of glass eels of 198 tonnes. Whereas the total production in 1994 for the same countries plus the Netherlands was around 494 tonnes. The largest difference between the 2 periods comes from Spain where 150 and 4 tonnes were reported for 1994 and 2004, respectively. This difference may be due to an overestimation of the production in 1994².

The relative abundance index, the variation of which is shown in Figure 7, is estimated between the maximum of the data series and the value of the catch in a given year. This illustrates the start of the downward trend, showing that the decrease in eel abundance began during the 1960s in the Baltic or Scandinavian area, followed by a reduction in recruitment in the south of the North Sea during the 1970s. This was followed by a rapid decrease of the arrivals of glass eels in the central area from the south of British Islands down to the Iberian Peninsula during the 1980s.

The trends of the relative abundance indices defined from official statistics and from scientific series of catch abundance show that the decrease of the intensity of the glass eel recruitment began sooner in the North of the colonization area than in the South (Figure 7).

² The series of statistics concerning glass eels landings provided by the Asturias Region in the framework of the INDICANG program give a figure of 8 metric tonnes for the fishing season 1995–1996 that confirms the level given for the Nalon River by the ICES group in 2006 (9 900 kg). So, it seems unrealistic to think that more than 100 tonnes of glass eel are caught off the Basque country and the Galician rivers, even if the small production from the Ebro River in the Mediterranean is added.



The decrease presently common to the whole area, and for the Mediterranean, has consequences for the purchase of the wild seed necessary for aquaculture and stocking. For European aquaculture, 2.5 kg of glass eels generally produce 1 ton of eel (7 pieces per kg). As European production is close to 10 000 tonnes of fish, around 30 tonnes of glass eels are necessary to support eel aquaculture each year, and the price has to stay below approximately 700 Euros per kilogram.

For restocking, the amount of glass eel purchased is roughly known, but the statistics provided by the ICES/EIFAC Working Group on eel don't take into account all national restocking programmes. Figure 8 (from ICES/EIFAC WG on eel, 2006)



presents the series of glass eels or elvers introduced in the European waters from the mid-1940s to the present. Figures are lacking from France, Spain, Italy, Ireland, and Germany where some restocking programmes exist.

There are some major efforts among the countries involved in restocking. For example:

- In Belarus, from 1956–2002, more than 56 million eels were released into 44 water bodies covering a surface area of 48 500 hectares (Petukhov, 2002). Since 1988 no regular introductions have been made.
- In Poland, from 1951 to 1980, an average of 18.2 million eels was released annually into 559 lakes. These introductions, according to Leopold and Bninska (1983), had an important impact on eel harvests.
- In Lithuania, the first stocking operations took place between 1928 and 1939 when 3.2 million elvers were released into lakes of the Vilnius region (Shiao *et al.*, 2006). Since the mid-1960s, Lithuanian lakes have been stocked with 50 million yellow eel juveniles representing an annual average rate of 1.1 million eels (Lozys, 2002).
- In Sweden, the stocking of lakes is an old tradition, beginning as early as the eighteenth century. From 1976–1980 about 1.5 tonnes of elvers were imported from France and stocked along the coast and in lakes. Starting from 1979, the Swedish Board of Fisheries allocated SKR425 000 (approximately US\$63 500) for annual restocking activities (Wickström, 1983).
- In Ireland, Moriarty (1983) detailed the release of 13.8 million elvers from 1960 to 1974 into Lough Neagh to increase production. The results suggest that at least a tenfold increase in catch elsewhere in Ireland could be achieved by expanding the existing restocking programme.
- In Denmark, a national stocking programme has been in place since 1987, financed through sport fishing licence fees. The seed are imported from southern Europe, pre-grown in local farms and released in brackish (75 percent) and fresh (25 percent) water bodies. In 2004, the programme was scaled down due to the poor harvests and the high price of glass eel (Pedersen, 2005).

TABLE 3
Variation in glass eels price from 1993–2006

Fishing seasons	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06	06/07	Mean monthly prices (€)
15 to 30/09	137					221	168								175
01 to 15/10	137				305	221	152	226				485		540	254
16 to 31/10	137			198	168	274	183	290				490	655	540	299
01 to 15/11	137	168	168	198	122	244	152	373	320			540	640	560	278
16 to 30/11	137	137	160	213	114	320	107	389	320	351		590	680	510	293
01 to 15/12	122	114	145	229	114	366	183	450	198	330	380	720	665	560	309
16 to 31/12	91	84	122	274	114	238	204	343	252	309	365	670	450	350	271
01 to 15/01	76	84	137	335	114	198	274	290	274	210	345	660	450	390	265
16 to 31/01	61	76	168	412	114	152	183	285	308	210	350	670	400	400	261
01 to 15/02	61	69	137	229	152	171	226	305	198	235	315	820	380	490	254
16 to 30/02	61	76	137	305	198	118	175	290	149	230	430	950	480	670	277
01 to 15/03	76	91	137	229	305	111	130	213	202	250	570	1 100	390		293
16 to 31/03	84	91	152	252	503	107	177	267		235	750	1 020	400		336
01 to 15/04	91	99	152	274	274	114	192	309		255	640	970	380		313
16 to 30/04	99		160	229	305	113	201	351			540	900	360		326
01 to 15/05	114		168	152	305	113	233	320			520	930	430		329
16 to 31/05			168		290	133		290				930	450		377
01 to 15/06			175		290			290				800	470		405
16 to 30/06								274		220		750	485		432
01 to 15/07												700			700
Mean annual price (€)	101	99	152	252	223	189	184	309	247	262	364	773	563	501	

Source: Nielsen, T., personal communication, 2007.

In recent years the price of glass eel has increased significantly due to the growing Asian demand and due to a decrease in the glass eel production by half since 1995 (400–500 tonnes compared to the current 200 tonnes) (Tables 3 and 4). This situation allows the glass eel fishery to retain its profitability even at low harvest levels, but creates difficulties for eel growers and fishery managers in finding the seed for aquaculture and restocking activities. A rapid price increase during the 2004 season impacted the restocking programme in Europe (e.g. Denmark) and most probably the overall profitability of the aquaculture sector.

Fishing seasonality

In the main areas of glass eel distribution, i.e. the Atlantic coast from the south of the British Islands down to Morocco and in the Mediterranean, migration occurs during the whole year as observed by Charlon et Blanc (1982) in the Adour River in the south of France, by Antunes (2002) in the Minho River in the north of Portugal and Sobrino *et al.* (2005) in the Guadalquivir in the south of Spain. However, the main fishing season occurs during a more restricted period as defined by fishing regulations or by economical constraints, such as an insufficient density of juveniles in the estuary for fishing to be profitable.

Fishing periods differ according to the river basin district: November to March in Italy, with a peak in January (Ciccotti, 2002), and in the southern part of France (Prouzet *et al.*, 2001). For the Adour River, the main fishing season shortened with the reduction in the eel resource (Prouzet, 2002). During the 1960s the length of the main fishing season was four months (from November to February). Currently the fishing season is no longer than two months, either November–December or December–January. On the Cantabrian coast of Spain, the main fishing season generally occurs between December and February (Garcia Flores, Herrero and de la Hoz Reguls, 2005).

In the southern part of the European Atlantic coast, the fishing season takes place earlier. For example, in the Guadalquivir estuary of Spain, the fishing season is between October and March of the following year, with peak fish densities between November and January (Sobrino *et al.*, 2005). The fishing season is generally later in the north of France. For example, in the Loire River, the main fishing season is between January and March, as in the Vilaine estuary (Feunteun *et al.*, 2002). In the Channel (Baie de Somme), the fishing season takes place between February and April, with March the best month (Rostiaux and Delpech, 2006).

In England and Wales, most of the glass eels are caught in the spring, but some pigmented elvers may be caught later in the season (Knights, 2002). In Ireland, glass eels are known to arrive off the Irish coast beginning in mid-December, but significant catch takes place in the estuaries from February to mid-April (Poole, 2002).

Handling procedures and equipment used for transportation

There is not a single standard procedure for handling European glass eels. As the methods of capture vary greatly from country to country (e.g. traps, dip nets, trawls), even from region to region, so do the ways of handling and transporting the fish. The commercial boats operating in French rivers are among the most representative way of handling the fry. The fishermen typically trawl for 5–25 minutes and deposit the catch on a plastic grid (mesh size 5 mm) on top of a holding tank (see Figure 6). The most active glass eels will immediately find their way through the grid while wounded and exhausted specimens will have to be helped with the aid of a brush. A variety of other small organisms such as shrimps, worms, fish, etc., find their way through the grid as well. Larger items are discarded overboard. The young eels are kept in the tank and the water is renewed, depending on the equipment onboard. After fishing the tanks are emptied into a fine net and the eel catch placed into buckets with a little water or into flat boxes if there is a substantial catch.

The eel catch is taken to a local collecting station, which is either a building situated along the river bank or a mobile station, e.g. a van with a tank and scale for weighing the catch. The eels are carefully drained of water, checked for bycatch and dead fish, and placed into the holding tank. A receipt is issued to the fisher, and once a week a payment invoice is issued based on the tickets collected, which are added up and multiplied by the “riverbank price”, i.e. the price paid to the fisher. The price can vary from river to river, depending on the quality of the fish supplied, which often depends on the fishing method used.

After resting, the live eels are retrieved from the holding tank and transported to the wholesaler following the removal of dead fish and bycatch. The wholesaler may employ a team of riverbank collectors who receive a regular salary and a bonus for every kilogram of eels collected. Alternatively, the wholesaler may simply purchase the fish from autonomous collectors. Dead fish are usually sold separately.

After a further resting period of 24 hours, any dead and damaged fish or remaining bycatch (mainly shrimp, nereid worms, eel fingerlings and other species of small fish) are removed. Wounded glass eels, usually called “swimmers” or “whites” (as they turn milky in appearance) are removed by hand nets or skimmers as they are likely to die during transportation or when released into the farming tanks. The fish are kept in the wholesale facility for 2–4 days depending on their quality, market prices and transport availability. The temperature in such holding tanks can be controlled, which is important at the beginning and end of the fishing season when the water temperature may exceed 10 °C. The correct temperature limits weight loss and pigmentation, the market preferring transparent glass eels rather than dark ones. Once the eels have recovered from fishing stress they are ready to be delivered to buyers, who are European eel farmers or Asian importers. The latter are mainly in China, which imports over 90 percent of all glass eels shipped to Asia.

Europe

The eels are usually transported in trucks fitted with specialized holding tanks or packed dry in polystyrene boxes and delivered by air or road to the final destination. Transport can last up to 36 hours. As eel catches have decreased recently, small trucks are usually used, e.g. 3.5 to 12 tonnes, fitted with 1 to 4 insulated tanks to prevent temperature fluctuations. Eighty percent of the trucks use pure oxygen instead of compressed air in order to reduce transportation stress and water turbulence from aeration. The trucks are also equipped with oxygen and pressure monitoring alarm systems. The trucks transport from 150 to 900 kilogram of glass eels. Payment is issued once the fish are safely delivered to the farm.

China

European eels are sold to importers, who buy import licences from the relevant government authority. Once the eels arrive in China, they are sold to distributors who transport the fish to the provinces where the farms are located. Chinese farmers are not in a position to import the fish directly due to strict foreign exchange regulations and transportation and organizational constraints. Furthermore the import licences are mainly in the hands of few large companies. The eels are initially cooled, weighted and dry packed into specially designed boxes for shipping. Packing has reached a high degree of technical sophistication and a team of 3 persons can pack up to 500 kilograms/hour (Figure 9).

The boxes are transported to the airport in refrigerated trucks, and transferred to the airline companies who are generally well informed on the delicate nature of the goods. The plane cargo hold is usually maintained at +5 °C during the flight. Customs clearance in Asia is carried out as quickly as possible in order to shorten the overall transport time. The maximum transport time to ensure good eel survival is around 38 hours, with an average time of 26 hours. When the fish arrive in Asia they are delivered to an unpacking facility usually located within an hour drive from the airport. During unpacking, the seller's agent is usually present to report on quality. The typical guarantee in China is a maximum 3 percent loss and a maximum deviation of 5 percent in the number of glass eels/kg, as the Chinese importers sell the glass eels to the local farmers by piece. Following this inspection process the fish are repacked within 4–6 hours after reception and transported to the Chinese provinces that farm the eels, mainly Fujian, Jiangxi and Guandong. Fish shipped to China are paid in advance by the importers.

Reliable techniques have been developed for the transport of glass eels to the farms and only unpredictable accidents cause severe mortalities, e.g. truck accidents, flight problems. Over 95 percent of the shipped eels make it to their final destination alive. The weak link is the capture methods used



in some areas. Mortalities up to 45 percent can still be recorded in some rivers in the north of France compared to the 10 percent reported in the southwestern part of France or the 2–3 percent loss reported in England. The fishing sector needs to reduce mortalities throughout its capture operations.

AQUACULTURE DEPENDENCY ON THE WILD SEED

Wild versus hatchery produced seed

Eel aquaculture is 100 percent dependant on wild seed and the supply of glass eels is decreasing. Some harvest areas seem to be declining more rapidly than others, but, as the European eel population must be considered as a whole, the overall supply is at risk. The collected seed material in Europe exceeds the needs of the aquaculture industry, and the excess supply is consumed in Spain as an expensive seafood delicacy (Table 4). If artificial breeding of the European eels becomes possible, it could still take many years before the necessary quantity of seed required for farming becomes available and can be economically produced.

During the 2004/2005 season, purchases from Asia started late when the glass eel supply was no longer available in sufficient quantity to meet the demand. This caused prices to rapidly increase and peak to an unexpected level of €1 150/kg. At this price the European farmers could no longer buy any glass eels to stock their facilities, as they could only afford to pay €700/kg (approximately US\$1 100/kg) and still remain profitable. If this situation had persisted for several seasons, European eel farming would have closed down.

The Asian eel farming industry is based on two species, i.e. *Anguilla anguilla* and *Anguilla japonica*. The local species is much preferred to the imported one especially in Japan as they perform better in terms of growth and survival rates. However, the supplies of *Anguilla japonica* had decreased considerably forcing eel farmers to find other supplies and the European eel began to be imported into Asia. The supplies of *Anguilla japonica* have started to increase again in recent years for unknown reasons, rising from the low catch of 15 tonnes in 2002 to over 100 tonnes in 2006.

Future of eel aquaculture

The European eel farming industry is stable and the production meets the current market demand. The industry however is not expanding; no new farms are being constructed, and the existing ones are in a reasonable to good economic situation.

The Chinese industry, on the other hand, has undergone a serious crisis over the last two years, as the intensive use of prohibited products, such as malachite green, was disclosed and all exports were banned from China to Europe, Japan, China Hong Kong Special Administrative Region (SAR), Republic of Korea and other Asian countries. Many eel farms had to cease operation as they no longer could sell their products. The import of European glass eels decreased in 2005–2006 and is likely to decrease even further (Table 4). The Asian eel market has suffered from this crisis as well, with customers being afraid of “potentially carcinogenic products” in the farmed eels. The Chinese eel farmers claim to have succeeded in raising eels without using such products. The market confidence will have to be bought back at high cost for the farmers, meaning that the Chinese eel farming industry is not likely to grow significantly in the coming 2–3 years. European glass eels, as long as they do not decrease further, will be able to supply aquaculture demand for at least the next 2–3 years.

If the Chinese eel farming industry had not faced this problem, the collection of European glass eels would not have been sufficient to meet demand. The Chinese importers would have turned their attention to the American species (*Anguilla rostrata*), and taken the available quantities there as well. Even with this new supply the shortage would not have been addressed and other eel species would have been tested.

TABLE 4
Glass eel harvest (in tonnes) and their use in aquaculture and direct human consumption

Fishing season	Total catches	Consumption in Europe	European aquaculture	Chinese aquaculture	China (% of total catches)
1993–1994	350	275	30	45	13
1994–1995	500	385	35	80	16
1995–1996	350	200	40	110	31
1996–1997	320	75	45	220	69
1997–1998	125	35	12	78	62
1998–1999	340	180	40	120	35
1999–2000	230	80	20	130	57
2000–2001	140	20	20	105	75
2001–2002	230	100	25	105	46
2002–2003	220	90	30	100	45
2003–2004	145	27	28	90	62
2004–2005	110	13	22	75	68
2005–2006	92	14	31	47	59

Source: Thomas Nielsen, personal communication, 2007.

Economic and technical implications of wild caught versus farmed seed

As there is no farmed seed available, comparison between wild and farmed seeds can only be estimated. If artificial reproduction of eels is achieved, it will still be questionable if the mass production can be realized and at what cost, compared to wild caught glass eels.

FISH FEED

Wild caught food

Eel farming in Europe relies entirely on wild-caught food: cod roe is used to wean the glass eels while artificial dry food, based on fishmeal and fish oil, is used for on-growing. In China, glass eels are weaned on cultured *Tubifex* worms for about one month, until they reach an average weight of one gram. They are then gradually adapted to an artificial pasty food for the rest of the farming process. Eels seem to be very sensitive to alternate protein sources and none of the tests conducted so far with non-animal protein sources have succeeded (Dana Feed, personal communication, 2007). Thus this species is still totally dependent on feed derived from wild-caught fish.

Cod roe – Most of this product is supplied by Danish fishmongers, who estimate the total quantity supplied to the eel farming industry at 20–40 tonnes per season. The cod (*Gadus morhua*) fishing industry easily supplies this quantity of roe and the price is less than €5/kg (approximately US\$7.9/kg). The product is supplied in frozen blocks of 20 kilograms. If the cod quota drops in the future, and insufficient roe supplied, this feed source can be replaced with blended mussels which is available in large quantity. Initial natural food supply for glass eels is available without a problem.

Fish oil used in Europe – Although information is not available on the fish species from which the oil is extracted, the feed industry indicates that supplies are plentiful and not at risk over the next 10–15 years (Dana Feed/Provimi, personal communication, 2007).

Fishmeal used in Europe – As with fish oil, this source is apparently not at risk in the near future. The species used are exploited “at a sustainable level” (Dana Feed, personal communication, 2007).

Fish oil used in China – China imports fish oil from Chile, Iceland and the United States of America. One of the species used to produce the oil is the Pacific cod (*Gadus macrocephalus*). With an annual harvest of around 400 000 tonnes this oil supply can be considered steady and reliable.

Fishmeal used in China – Fishmeal imported in China originates from many countries, e.g. Chile, Russia, Singapore and the United States of America. The supply is plentiful and local feed plants do not expect any shortage, with various fish sources are used as raw material. As the eel farming industry has been profitable, eel farmers can afford higher feed prices than other fish farmers, assuring their access to feed supplies.

Artificial food

As the initial food used to wean the glass eels has a high water content (≈ 70 percent) it is important to rapidly switch over to a more nutritive food in order to obtain better growth. Artificial feeds for glass eels do exist, and tests have been conducted to compare efficiency of feeding and growth on eels started on natural food compared to eels directly fed with artificial food. The tests show that a higher percentage of elvers weaned on natural food start eating the artificial feed, resulting in better growth and survival rates. Use of natural food for on-growing is unsuitable for the farming techniques in both Europe and Asia. Even in Japan, where eel farming has the longest history, the natural food items used to grow eels (fresh fish, silk worm pupae, fish waste, etc.) have been entirely replaced by artificial feeds (Matsui, 1980).

The artificial food used in Europe is mainly extruded pellets, distributed via self feeders or automatic feeding machines. Feeding may also be completely automatic and managed by computer programmes. In Asia, most eel farms use a pasty feed prepared twice daily in kneading-machines. The paste is made available to the eels on floating frames or trays attached to the sides of the culture tanks.

Food resources

None of the feeds used to produce eels, apart from the cod roe, was previously used for human consumption.

Cod roe – The quality of roe sold to eel farmers is “pierced and damaged roe” plus “small roe” as large and whole roe is sold as a delicacy. The quality used for eel was previously sold to the canning industry or exported for production of *tarama* (a traditional appetizer – roe mixed with either bread crumbs or mashed potato with addition of lemon juice, vinegar and olive oil) in Mediterranean countries.

Fish oil used in Europe – This was previously used for other fish or animal feeds.

Fishmeal used in Europe – This was previously used for other fish or animal feeds.

Tubifex worms used in China – These were previously used for the aquarium food industry as both frozen or dried.

Fish oil used in China – This was previously used for other fish or animal feeds.

A significant increase of global eel production is not anticipated due to the limited supply of glass eels. Hence the supply of wild-caught feed is sufficient to meet the current eel farming demand.

ANTHROPOGENIC IMPACTS

Analysis of the recruitment trends in the northern part of the eel distribution area, and particularly in Sweden and in the Baltic area, show that recruitment and escape indicators started to decline well before the 1970s (Anonymous, 2002).

One of the major causes of declining populations is habitat fragmentation due to the construction of obstacles to eel migration. More than 25 000 dams were built worldwide in the twentieth century. In the European Union it is estimated that 60–65 percent of all rivers have some form of obstacle which restrict eel accessibility to the middle and upper reaches of the rivers. This effect has been experienced more severely in the peripheral zones of the eel distribution area, in particular in Scandinavia where hydroelectric facilities have been in place for many years. It is highly probable

that these changes to the rivers had a catastrophic effect on the production of yellow and silver eel sub-adults. By the end of the 1940s this area alone experienced a marked reduction in small eels and a decreased in eel harvests in the Baltic a decade later.

In France, there has also been substantial disruption of rivers, including dams built near river mouths to prevent the tidal flow from moving upstream. These structures prevent glass eel from migrating upstream and increases the rate of exploitation of the fishery just underneath the dam, e.g. in the Vilaine estuary glass eel exploitation is >90 percent of the population (Anonymous, 2002).

The negative effect of these dams on eel production is exacerbated by water turbines that dramatically reduce the survival of silver eels during the downstream migration. Mortalities depend on the type of turbine used, the position of the water intake compared to the river axis, the presence of protective screens and hydrostatic pressure differences. The problem becomes particularly complicated when there are several hydroelectric power stations along the same river. Prignon, Micha and Gillet (1998) estimate that on the Meuse River direct mortality due to the migration through turbines was 34–45 percent for male eels and 40–63 percent for females. Dönni, Maier and Vicenti, (2001) also showed that the cumulative eel mortality after the passage through 13 hydroelectric power stations on the Rhine is 92.7 percent. Eel survival is directly linked to free migration upstream and downstream.

The decrease in wetlands also impacts eels. Agricultural developments to increase water extraction or diversion for irrigation have caused severe degradation of lower drainage basin wetlands. It is estimated that between 30–40 percent of the 268 million hectares of cultivated land in the world are irrigated from surface water. In France the irrigated agriculture areas in the Garonne, Charente and Dordogne catchments have increased five-fold, from 100 000 hectares in 1970 to 500 000 hectares in 2000, while on the Adour the area increased four-fold (Teyssier *et al.*, 2002; Prouzet, 2002, 2003a).

Development of agriculture on these wetlands has also been accompanied in the increase use of chlorobiphenyls, heavy metals, and organochlorinated pesticides which are easily accumulated in the fatty tissues of the eels. A study in Belgium showed that 80 percent of the eel samples examined exceeded the acceptable polychlorinated biphenyls (PCB) threshold of 75 µg/kg (Goemans and Belpaire, 2002). The impact of this contamination on the physiology of eel and, in particular, on its reproduction, remains undetermined.

The introduction of *Anguilla japonica* into the Mediterranean in the 1980s caused the appearance in Europe of the hematophagous nematode *Anguillicola crassus* (Peters and Hartmann, 1986). This nematode resides in the wall of the eel swim bladder and probably reduces its ability to ensure hydrostatic balance at the time of the migration towards the Sargasso Sea (Möller *et al.*, 1991). The parasite is now widespread in Europe, with rates of infection of 55 percent in the Adour River (Anonymous, 1998) and close to 100 percent in many countries (Kennedy and Fitch, 1990). Fishing mortality varies according to country and river basin. The quantity of bycatch during glass eel fishing depends mainly of the location of the fishery, with greater bycatch in the marine environment than in brackish or freshwater. Most fishing boats are equipped with a sorting device which allows the removal of unwanted organisms (Figure 10). This kind of simple equipment limits the impact on non-target species.

FIGURE 10
Typical eel bycatch from estuaries and coastal waters in Europe



SOCIAL AND ECONOMIC IMPACTS OF EEL FARMING

Social impacts

From fisherman to consumer

In France, approximately 1 300 professional fishers are directly involved in glass eel harvesting in marine and continental waters (Castelnaud *et al.*, 2005). A leisure fishery also exists, but the sale of the eels is forbidden. Illegal fishing is an important problem on some estuaries, e.g. the Gironde and Loire. Illegal catches are difficult to estimate, but could be of the same order as the legal catch on some rivers.

In England, the glass eel harvest requires a licence that costs £63 (approximately US\$126) and in 2005 805 fishers held a licence (Pawson *et al.*, 2005). Fishing is only allowed using handheld dipnets. In Spain, around 682 fishers harvest glass eels in the Basque country (Diaz and Castellanos, 2005). These fishers are not considered professional, but are authorized to sell their catch. In Asturias, on the Nalon River, there are about 50 eel boats licences for boat fishing and between 150 and 200 fishing licences for land-based operations. On the Esva River, there is also a professional land-based fishery, but the number of fishers is not recorded (Garcia-Florez, Herrero and de la Hoz Reguls, 2005). Eel fishing exists also in the Guadalquivir (Sobrinho *et al.*, 2005) in Andalusia, but the fishing effort and the catch have not been quantified. On the Mediterranean coast, a small fishery also exists on the estuary of the Ebro River in Catalonia (Spain).

In Portugal, glass eel harvest was banned in 2000, except in the Minho River on the boarder between Spain and Portugal (Coimbra *et al.*, 2005). However, the activity still continues to some degree as “Portuguese glass eels” are often available on the market. In Italy the number of licences is difficult to assess because there is no central registration (Ciccotti, 2005). There are possibly around 10 companies fishing glass eels in marine waters.

In Morocco the eels are collected using large traps that stretch across the river. There are 200 to 300 fishers collecting glass eel, and the activity supports the livelihoods of at least double this number. The total quantity of eels collected per season is around 3 tonnes, but due to poor conditions and materials used, only 1/3 usually survive following collection. All the fish are exported despite a national regulation stipulating that 75 percent of the glass eel harvested in Morocco are to be farmed locally.

The total number of eel fishers in Europe is estimated to be between 3 000–3 500, mainly in France, United Kingdom and Spain. The European eel fishers sell their catch to middlemen, of which there are around 80–100. Wholesalers purchase the fish from the middlemen and then place glass eel batches of 80–500 kilograms on the market as buyers are not interested in batches <80 kilograms.

In order to deliver glass eels to the European farmers and to the Asian importers, the suppliers need to run a fleet of transport trucks, have skilled workers and funds to purchase the glass eels. Only larger companies are able to assemble these means. There are 8 wholesalers in Spain, 9 in France and 2 in the United Kingdom. Wholesalers employ between 2–15 persons, and are often family-based companies. Some companies only work with glass eels, while others also trade in all sorts of seafood. The glass eel fishery alone engages around 3 300–3 900 people, not including those working in the aquaculture sector.

There are approximately 50 eel farms in Europe (26 in the Netherlands, 8 in Denmark, 3 in Germany, 4 in Spain, 2 in the United Kingdom, 2 in Sweden and 2–3 in Eastern Europe) and around 1 000 farms in Asia raising the European eel. In Europe, most farms sell their product to eel traders, mainly from the Netherlands as the size of the eels (i.e. 130/150 g) best match the Dutch market. Smaller farms sell all or part of their production directly to customers, as live, fresh and gutted, or as smoked, and obtain a better price for their product. The traders buy several tonnes from the farmers,

grade the fish, sell the larger ones to Denmark or Germany, and the rest is smoked for the Dutch customers and sold as whole smoked eels or filleted smoked eel.

In China, the domestic demand for the end product is growing but currently only a small fraction of the production is sold locally. Most eels are exported, with Japan importing almost 80 percent of the production. The eels are exported live, gutted and frozen or prepared as *kabayaki* in China-based processing plants. The eels shipped to Japan undergo a severe health and quality inspection for possible contaminants and prohibited products before being allowed to enter the country.

The eel fishers are nearly all men, usually assisted by their wives or other family members. In France, they need to hold a "Capacity Certificate", be 18 years old and have acquired at least 12 months work experience on board of a fishing boat. French glass eel fishers make a good living and generate almost 90 percent of their annual income. The eel wholesalers in France are mostly based in the Basque country where most of the eel are traditionally sold to Spain. The number of companies trading eel is decreasing as the market is very competitive and many small family-size companies are unable to cater for the Chinese market.

Aquaculture impact on the eel market

Until 1985, glass eels were either used for direct human consumption or for restocking programmes. Supplies were so plentiful that in the early twentieth century the eel fry were fed to poultry and used to produce glue. Whole train wagons of glass eels destined for Spain were typically loaded in Nantes, France, with 50 kilogram jute bags of eels. The main source of glass eels was France and the fish were caught and collected around the main estuaries of the Atlantic coast and transported by trucks to holding stations along the French/Spanish border. When conditions were favourable, the trucks were reloaded to deliver the fish to processing facilities mainly located in the village of Aginaga in Spain.

From 1985 to 1993, European eel farmers purchased about 10 percent of the glass eels collected without affecting the overall market price of the commodity. The average price during this period was €40/kg (approximately US\$63/kg) although adverse climatic events and festivities such as Christmas, New Year and San Sebastian day affect the price of the glass eels. Only few people or suppliers were interested in the aquaculture market for glass eel and supplied the European farmers during this period.

In 1993 China started to purchase the European glass eel (*Anguilla anguilla*) because the supply of the local *Anguilla japonica* was insufficient and prices had risen considerably. From 1993 to 2006 the average price was €300/kg (approximately US\$474), with peaks of €1 150/kg (approximately US\$1 816). The European glass eel traders could no longer ignore the demand generated by the aquaculture sector which was ready to pay much higher prices. The cooked eel market could not afford such prices and was only supplied with poor quality eel or the dead eel.

In the early 1990s the overall eel market for human consumption became very weak, and many eel farms in Europe and Asia were forced to shut down. A further crisis occurred in the 1998/1999 season when large quantities of farmed Chinese eels, following the imports of 200 tonnes of glass eels in 1996, flooded the market causing the eel price to drop by 50 percent. This resulted in the closure of additional eel farms throughout the producing nations. In the 2003/2004 season the Chinese industry somewhat recovered due to the lack of both *Anguilla anguilla* and *Anguilla japonica*, and importers paid prices of up to €1 150/kilogram (approximately US\$1 816) of glass eels.

Eel aquaculture has sustained a fishing industry that would probably have ceased to exist if it continued to be based only on the consumption market. With the pre-1985 prices of less than €40/kg (approximately US\$63) and current quantities of approximately 150 tonnes per season, the glass eel fishery would not be economically viable. Price levels created by aquaculture demand maintain the fishery. The companies

involved in the cooked eel industry have had to reduce their staff, or simply close down, while others started the production of glass eel *surimi* products.

The impact of farmed eels on wild-caught eels arises because Dutch traders pay a higher price for farmed eels than wild eels. The farmed eels are in fact more suitable for the smoking industry due to the higher fat content, standard sizes, year-round availability, regular supplies and do not have the typical “muddy” taste which is often the case in wild fish. Furthermore, wild eels are also more susceptible to stress, often damaged following fishing (tail damage, mouth damage, etc.) and may experience high mortalities during transportation, grading or storage.

Employment and skill issues

Eel farming has generated new employment opportunities in Europe, but on a limited scale, as the farming technology used does not require a large team of workers and technicians. In the European smoked fish processing sector the farmed eel replaced the wild eel and therefore no major employment changes occurred. On the other hand eel farming in Asia has created significant employment in both the farming and processing sectors (Figure 11).

The transition of the fishing industry to eel aquaculture did not much affect the fishers as the final market destination of the glass eels simply changed, with buyers mainly from the farms rather than the processing plants. However, the shortage of glass eels brought about the banning of non-professional harvesters (e.g. in France) and forced many out of the fishery.

With aquaculture now so critical to this industry, the quality of the glass eels harvested and a reduction of eel mortality is of utmost importance. In spite of this, only few of the French fishers have really made an effort to supply better quality fish to the riverbank middlemen. Most of them are only concerned by the quantity of fish collected, rather than quality. If there was a real price difference between dead and live fish, or even between good and bad quality, the fishers would quickly react to this. The laws regulating the fishery including the net size and boat engine permitted are not adequately enforced.

Economic issues

Market evolution

Eel fishers can be considered as the main beneficiaries of the development of eel aquaculture activity. Without this evolution, the glass eel fishery would have

become uneconomical and would probably have ended. The fishery is in fact sustainable only if the price per kilogram of eel is higher than €200 (approximately US\$316). As the price per kilogram increased considerably due to the demand from the aquaculture sector most of the estuarine and fluvial fishers are making a decent living. Out of the approximately 15 major wholesalers before aquaculture took over the market, 7 have completely stopped trading glass eel or do not exist any longer, 5 have lost market share, and 3 are performing well. Three new companies have started exclusively based on supplying the aquaculture market.

FIGURE 11
Workers in a *Kabayaki* factory gutting and preparing the eels



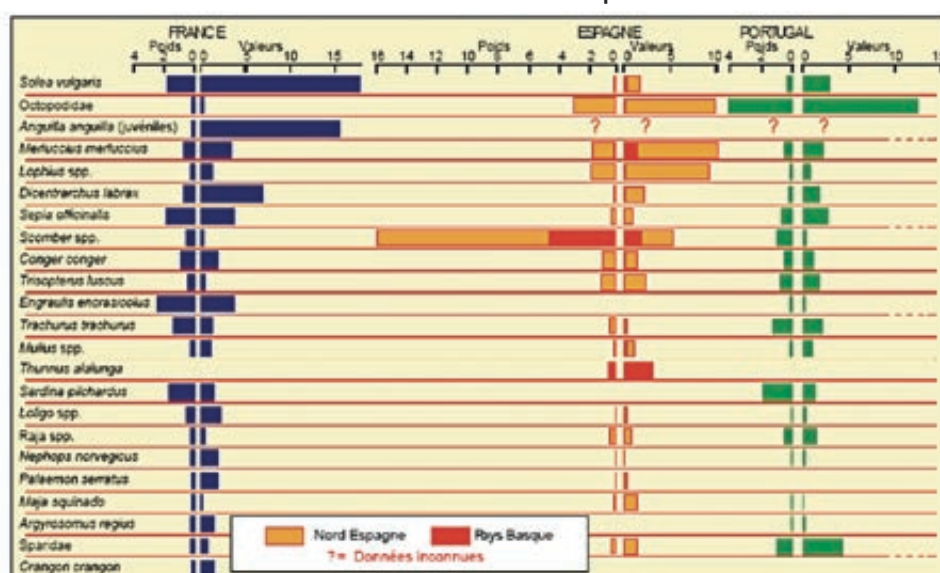
TABLE 5
Importance (in percent) of glass eels on the total turnover of the estuarine fishery on the Adour river from 1987 to 2000

	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Turnover (€1 000)	1 179	1 049	952	581.9	449.8	1 373	809.6	395.3	697.4	671.9	1 115	446.8	1 213	1 471
Glass eel	40.0	53.1	70.6	58.7	30.0	65.4	45.5	43.7	72.0	59.6	74.3	52.1	75.8	80.4
Migratory salmonids	27.3	26.9	7.2	16.1	21.4	11.8	15.3	18.5	7.3	4.9	4.9	11.5	7.2	6.8
Sea lamprey	14.8	1.3	6.2	9.5	19.1	14.2	23.2	2.8	2.9	10.1	12.7	22.0	7.4	6.8
Shad	7.6	7.0	5.3	4.8	14.4	2.4	3.9	15.2	6.3	9.8	3.5	7.0	6.2	3.9
Miscellaneous spp. ¹	10.3	11.7	10.7	10.9	15.1	6.2	12.1	19.8	11.5	15.6	4.6	7.4	3.4	2.1

Source: Prouzet et al., 2001.

¹ Miscellaneous fish species include European seabass, yellow eel, Gilthead seabream, mullet.

FIGURE 12
Distribution of the main species caught by the small inshore fisheries along the Atlantic coast of continental Europe



Source: Léauté et al., 2002.

Economic dependence of the small-scale fisheries

The eel fishing activity is conducted by different groups of fishers generally carrying out also other fishery-related activities such as oyster farming or sea fishing. Nevertheless, the small-scale glass eel fishery constitutes a major economic activity for most of the fishers involved as demonstrated by the Adour River (Table 5). On a larger scale, the EU project on the “Caractéristiques des petites pêches côtières et estuariennes de la côte atlantique du sud de l’Europe” (Pêches Côtières et Estuariennes du Sud de l’Europe – PECOSUDE) was undertaken to assess the economic impact of inshore and estuarine fisheries from the Loire estuary (France) all the way to the south of Portugal (Léauté, 2002). Among the 200 identified species or group of species landed along the investigated area, 7 species represented almost 53 percent of the total value in 1999. Of these, the European eel (especially the glass eel stage) ranked second in value along the French coast (Figure 12).

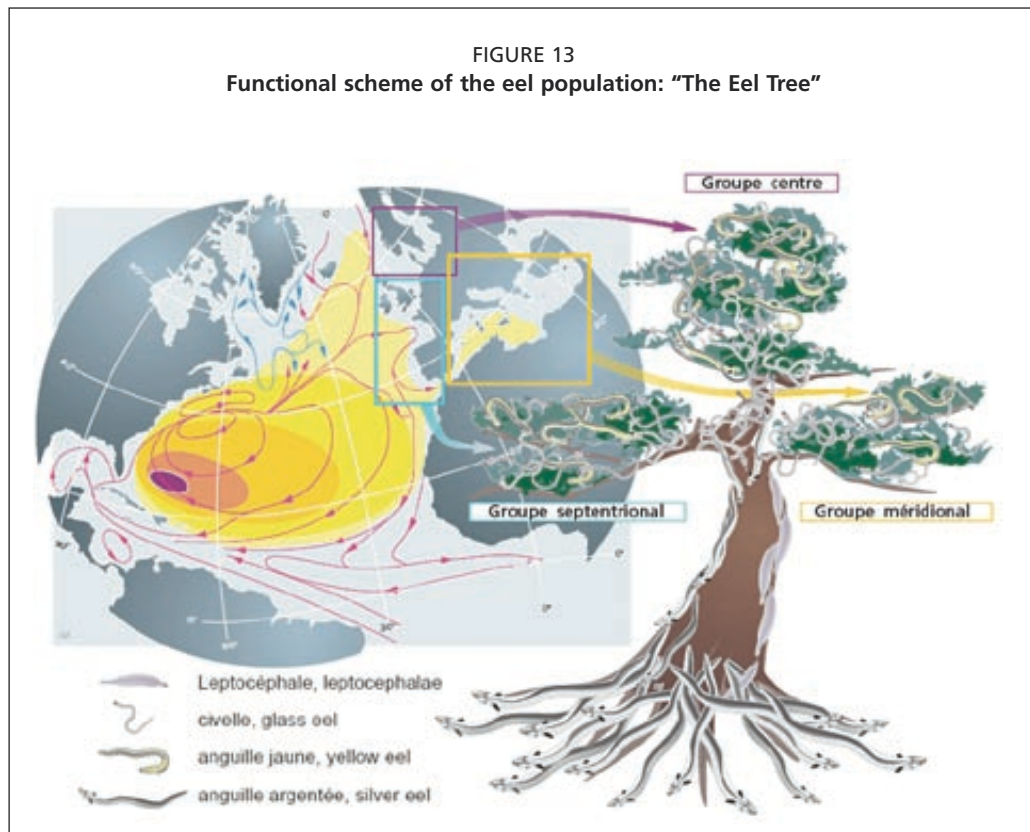
MANAGEMENT

Comparing the European eel population dynamics to a tree, its roots are in the Sargasso Sea, the rising and descending sap in the trunk and the main branches is represented by

the North Atlantic circulation, which spread the leptocephali and glass eel to North Africa and European coast. The leaves represent the different catchments where elver, yellow and finally silver eel are produced and contribute to feed the spawning stock in the roots of the eel tree (Figure 13). This helps to understand that to have a real impact on the future eel population, it is necessary to manage the stock not only at the scale of the catchments, i.e. the management unit corresponding to one leaf, but also to a larger scale corresponding to the canopy that represents the different areas of colonization. This scale and complexity of management is difficult to organize and requires coordination among all EU states exploiting the resource.

In order to manage and restore the eel population, which is considered as endangered and included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Council of the European Union made a proposal for a Council Regulation establishing measures for recovery of the stock of European eel (13139/05 Pêche 203 – COM(2005) 472 final). This regulation would establish a framework for the protection and sustainable use of the stock of European eel of the species *Anguilla anguilla* in EC maritime waters and in the estuaries and rivers of Member States that flow into the seas in ICES areas III, IV, VI, VII, VIII and IX or into the Mediterranean and Black seas.

The plan proposes seasonal closures in order to reduce catch by 50 percent with an exemption allowed only if a long term management plan is established. This objective is defined as an escape to the sea of at least 40 percent of the biomass of adult eel relative to the best estimate of natural escape defined according to: historical data or by habitat-based assessment of potential eel production, in the absence of anthropogenic influences or with reference to the ecology and hydrography of similar river systems. The management plans may contain different measures, such as fishery regulations, restocking, improvement of river habitats, temporary switching off of hydroelectric power turbines, etc.



The eighth article is of particular interest: “if a Member State operates a fishery on glass eels, it has to guarantee that 60 percent of all glass eels caught during the whole year are utilized as part of a restocking program in European inland waters having access to the sea, for the purpose of increasing the escapement levels of adult silver eels. In order to ensure that 60 percent of glass eels caught are used in a restocking programme, Members States must establish an appropriate reporting system.”

That implies together with the reduction of the catch, a major decrease of the production of wild seed available for export to Asian countries. The evaluation of the efficiency of the management plans has to be assessed and for this reason a project called “Abundance and colonization indicators of European eel in the central part of its colonization area (INDICANG)” is being undertaken.

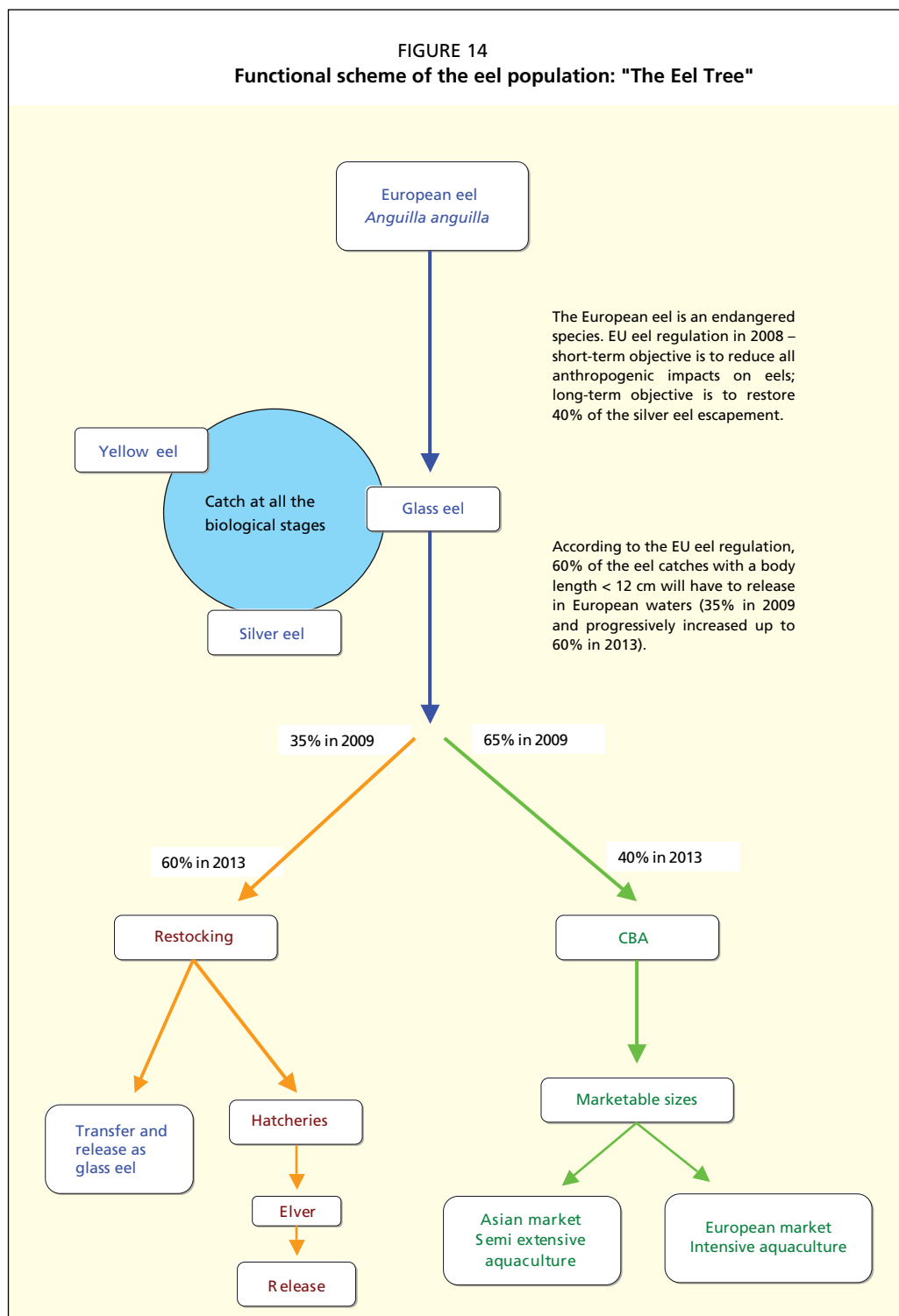
The diversity of the situations is such that each production unit should be considered separately. This approach was largely recommended by the scientific community, as it makes possible a systemic analysis. Fishing activity is not the only factor affecting eel populations. Other causes impact aquatic productivity, e.g. exploitation of the water for energy needs, exploitation of wetlands for urban and agricultural needs. Local scale efforts are insufficient because a restoration of the habitats and eel resource in only one catchment area cannot lead to a restoration of the resource on a European scale taking into account the diverse structure of the population. The implementation of a network of pilot catchment areas projects will allow a broader approach on a European scale, e.g. on a set of rivers between the Cornwall and the north of Portugal, as proposed in the INDICANG project (Prouzet, 2004).

CONCLUSIONS

The biological cycle of the European eel is not yet replicated under artificial conditions, meaning that the removal of seed from the natural environment is still necessary to supply the aquaculture sector. This species is presently considered endangered and in order to manage and restore eel stocks, the EC is defining a regulation to establish measures for the recovery of its stocks (Figure 14).

Recent research indicates that the successful reproduction of the European eel will require a further decade for it to be carried out on a large scale, which means that eel farming will have to rely on wild-caught juveniles until then. Collection of glass eels will increasingly become uncertain, particularly if the eel population continues to decline at the present rate. In this case, the priority will be to ensure the natural colonization of glass eels migrating through the estuary of a given catchment area. If some catchments receive a surplus of natural recruitment a portion of the glass eels arrivals will be assigned to the stocking of rivers or lakes in Europe with insufficient recruitment. This stocking will be made either by the direct introduction of glass eels in rivers or by the release of elvers pre-grown in hatcheries. In both cases, strict sanitary controls would have to be enforced.

To implement this plan, the EU will have to fund the purchase of wild seed from fishers and elvers from eel farms. Government funding would ensure implementation of the plan and ultimately integrate eel production with natural recruitments to increase spawning stock in open waters. Fishing restrictions would protect these stocks. This also implies a transparency of the marketing networks. The European regulation proposes a decrease in glass eel harvest, and restrictions on the export outside the natural area of eel colonization. A restriction of 60 percent of the catch has been made (35 percent in 2009, to reach 60 percent in 2013). If this becomes law, it is highly probable that supplying glass eels from Europe to the Asian market will be greatly disrupted.



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Capture-based aquaculture of bluefin tuna

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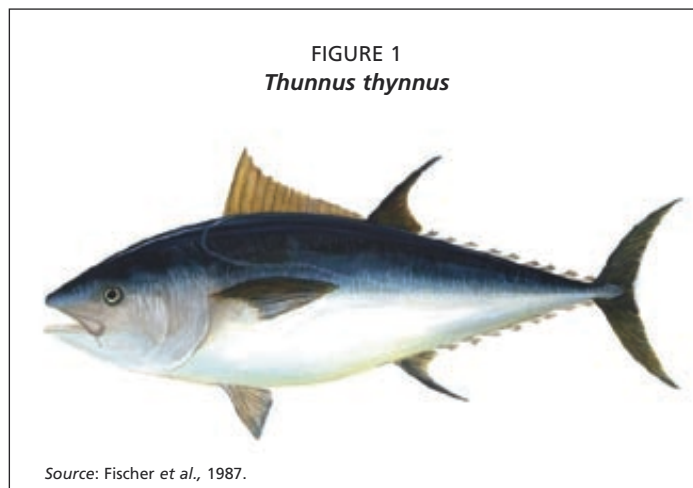
SUMMARY

Tunas belong to Actinopterygii, order Perciformes, family Scombridae which contains about 33 species and sub-species. The four species of high commercial interest for fisheries and capture-based aquaculture are *Thunnus thynnus*, *Thunnus orientalis*, *Thunnus maccoyii* and more recently *Thunnus albacore*. This paper focuses on *Thunnus thynnus* with references to the other tuna capture-based species and is organized in three main sections:

- Species description: a description of the taxonomy and distribution, habitat and biology, schooling and migration movements as well as feeding behaviour by size.
- Fisheries: a description of the fisheries, the global catch in relation to the main catching areas and the main gear used; and
- Capture-based aquaculture: fishing techniques, season and catching size, rearing techniques, aquaculture sites, feeding, harvesting and marketing practices, along with a review of the principal environmental, social, economic, market and management issues.

The further expansion of *Thunnus thynnus* capture-based aquaculture (CBA) is considered viable in the short term. However in the long term, sustainability may depend on the economically viable completion of the full life cycle (i.e. reproduction); improvements in the artificial feed formulation to reduce baitfish consumption and improve the feed conversion ratio (FCR); expanding markets beyond the Japanese market; and reducing illegal, unreported and unregulated (IUU) fishing. Furthermore, farmers need to follow best procedures to ensure traceability of traded tuna. There is also an urgent need to determine precisely the size and age composition of the fish destined for the farming operation as the current lack of biometric information makes stock assessment, and hence effective management and conservation of the bluefin tuna resource, difficult.

The Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) indicated in its 2006 stock assessment report that the spawning stock biomass continues to decline while fishing mortality is increasing rapidly, particularly for large fish. The growing need to respond to the global decline of most wild bluefin tuna fisheries will be a major driving force in the development of reliable technologies for large-scale production of juvenile tuna, for both commercial food production and fisheries enhancement programmes. As these technologies improve, the economics of full cycle farming should also improve, and quite possibly result in changes in the market structure for hatchery-produced fish.



SPECIES DESCRIPTION

Taxonomy and distribution

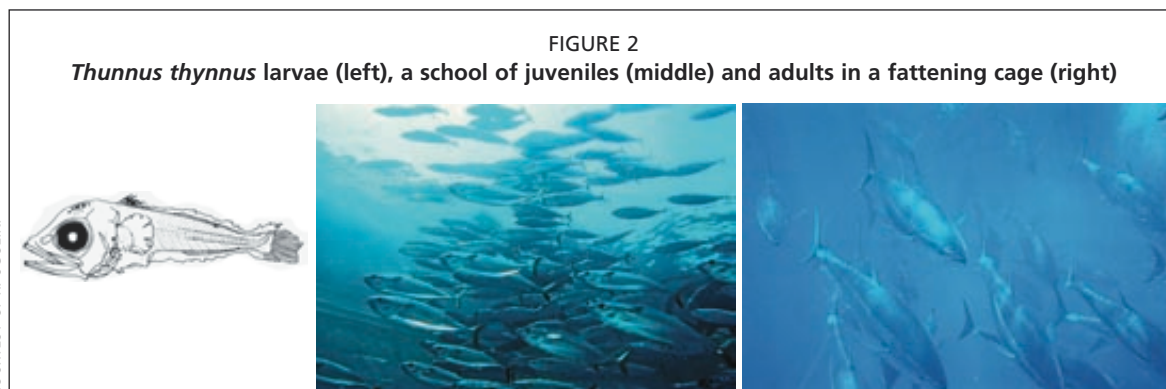
Phylum	– Chordata
Subphylum	– Vertebrata
Superclass	– Gnathostomata
Class	– Osteichthyes
Subclass	– Actinopterygii
Infraclass	– Teleostei
Superorder	– Acanthopterygii
Order	– Perciformes
Family	– Scombroidae
Genus	– <i>Thunnus</i>
Species	– <i>thynnus</i>

The bluefin tuna was first described by Linnaeus in 1758 as *Scomber thynnus*. Many other denominations followed, such as *Thunnus vulgaris* and *Thunnus thynnus*. One capture-based aquaculture tuna species is considered in this paper – the northern bluefin tuna (*Thunnus thynnus*) (not including *Thunnus orientalis*) (Collette, Reeb and Block, 2001), with reference to the southern bluefin tuna (*Thunnus maccoyii*). The *Thunnus thynnus* (Figure 1) is found in Labrador, Canada and continues south to the Gulf of Mexico and the Caribbean Sea and also off the coast of Venezuela and Brazil in the Western Atlantic. In the Eastern Atlantic it occurs from the Lofoten Islands off the coast of northern Norway south to the Canary Islands and the Mediterranean Sea. There is also a population in South African waters.

Habitat and biology

Northern bluefin tuna are large pelagic marine fish. The juveniles are encountered in epipelagic waters whereas large tunas tend to be mesopelagic and are found also in deeper and cooler waters. The species has considerable thermal tolerances, as it can be found in waters as cold as 10 °C, as well as in tropical areas (Brill, 1994). Generally the most critical environmental parameters for these large pelagic fish are sea surface temperature and the levels of dissolved oxygen and salinity. The species has been observed both above and below the thermocline. Juvenile fish tend to live near the surface.

The following three growth stages can be distinguished: i) larvae – recently hatched individuals which are considerably different in appearance from juveniles or adults; ii) juveniles – similar in appearance to adults, but sexually immature; and adults – sexually mature fish (Figure 2). The maximum reported weight of an adult specimen has been 684 kilograms, with a total length of 458 cm. The species seems to have an average lifespan of around 15 years, while the longevity for both the Atlantic and the southern



bluefin tunas was estimated at around 20 years (Cort, 1990). For adults natural mortality rates range from 0.2 to 0.6, while natural rates for juveniles are higher.

Schooling and migration

All bluefin tuna species move constantly in search for food and to maintain a constant water flow over their gills. The Atlantic bluefin (*Thunnus thynnus*), pacific bluefin (*Thunnus orientalis*), and southern bluefin (*Thunnus maccoyii*) tunas all migrate seasonally over long distances between temperate waters, where they feed, and tropical waters, where they spawn.

Spawning of all three species is generally restricted to relatively restricted areas in temperate and tropical waters.

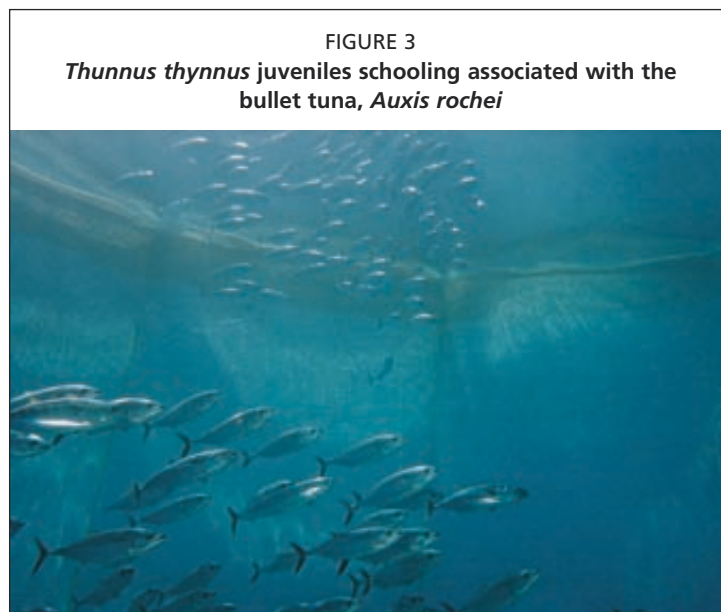
Thunnus thynnus may form giant schools spreading over several nautical miles when migrating into the Mediterranean Sea to spawn during the summer months. Most bluefin school according to their size, however it is not unusual for different size size-groups to school together. Juveniles are, therefore, often associated with smaller tuna species such as the skipjack or bonito (Figure 3). While schooling is believed to be sight-oriented, schools have been observed at night.

Bluefin tuna are excellent swimmers and can swim at high speed for long periods as they are able to absorb and utilize large amounts of oxygen. Their bodies are designed for high performance at both sustainable and burst swimming speeds (Dickson, 1995). Tuna must swim constantly to satisfy their oxygen requirements in order to stay alive. Their swimming pattern seems to be influenced by both the distribution of food and the need to return to their ancestral spawning grounds at the appropriate time. To efficiently transfer oxygen from the gills to the other body tissues, tunas have hearts that are approximately 10 times the size of those of other fish, relative to the body weight, and blood pressure and pumping rate about three times higher.

Tunas have two types of muscle, white and red. The white muscles function during short bursts of activity, while the red muscles, which have a relatively large mass, allow the fish to swim at high speeds for long periods without fatigue, as demonstrated by tagging studies with conventional and sonic tags (Joseph, Klawe and Murphy, 1988; Bushnell and Holland, 1997).

Feeding

Tuna larvae live in warm surface waters and feed primarily on zooplankton, including small crustaceans and the larvae of crustaceans, fishes, molluscs and jellyfish. Tuna larvae are preyed upon by zooplankton foragers, such as larger larvae and early juveniles of other pelagic fish. Juvenile and adult tuna generally prey on fish, squid and crustaceans. The larger specimens, which feed on pelagic fishes, are positioned at the top of the trophic web and locate their prey visually. To satisfy their nutritional requirements tunas have to swim long distances. Their type of locomotion is particularly well adapted to the search for prey in large water volumes with the least expenditure of energy. Tuna break up schools of prey, producing disorientation and straggling (Webb, 1984; Partridge, 1982). When prey is detected, the tuna changes their behaviour and have a general increase of activity, e.g. increase in swimming speed,



change in swimming pattern and energetic pursuit to obtain smaller schooling fish such as anchovies.

Reproduction

The spawning of *Thunnus thynnus* has been so far detected in only two areas: the Mediterranean and the Gulf of Mexico. In the Gulf of Mexico, spawning occurs from April to June when the water temperature is 25–30 °C and in the Mediterranean from May/June to August. Karakulak *et al.* (2004a; 2004b) reported bluefin spawning in the Levantine Sea (Eastern Mediterranean basin) with a peak in the activity in May.

Sexual maturity of the Atlantic bluefin tuna is reached at the age of 5 to 8 years, while in the eastern Atlantic maturity is reached earlier, at 4–5 years. Scientists have found that in the Balearic Islands (Mediterranean) bluefin tuna are able to spawn from 3 years old (Abascal, Megina and Medina, 2003). Bluefin tunas may release from 5 to 30 million eggs and spawning occurs in open water close to the surface and in areas where the survival expectations of the larvae is highest.

BLUEFIN TUNA FISHERIES

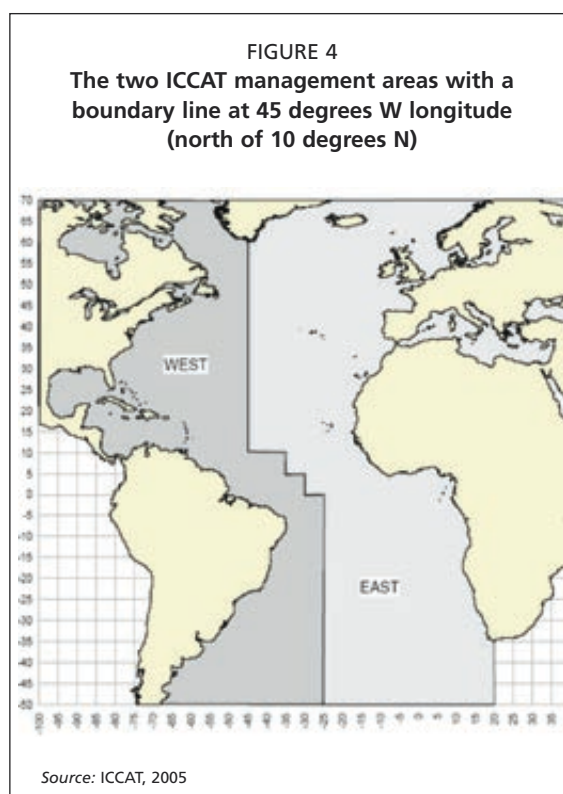
Thunnus thynnus is the most demanded and expensive tuna species. The fishery is regulated by the International Commission for the Conservation of Atlantic Tunas (ICCAT) which is responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and adjacent seas. Since 1982 the Commission has managed Atlantic bluefin tuna in two areas with a boundary line at 45 degrees W longitude (north of 10 degrees N) (Figure 4).

As a result of overfishing, beginning in 1982 the fishery in the Western Atlantic management area has been controlled by restrictive catch limits. Catch limits have been in place for the Eastern Atlantic and Mediterranean stock in 1998. The Commission established a total allowable catch (TAC) for both stocks.

The *Thunnus thynnus* global catch shows a considerable yearly reduction. In 1996 it peaked at 52 664 tonnes and dropped to 31 577 tonnes by 2004 as a result of the ICCAT quotas (Figure 5). However, the Standing Committee on Research and Statistics (SCRS) of the Commission affirms that considerable overfishing still goes undetected.

According to the ICCAT global catch statistics for the Western Atlantic tuna stock from 1995 to 2004, the lowest catch was recorded in 2004 at 1 644 tonnes, while the highest was in 1999 at 3 550 tonnes. For the Eastern Atlantic stock, the lowest catch was reported at 29 933 tonnes in 2004 and the highest at 50 274 tonnes in 1996 (Figures 6 and 7).

Thunnus thynnus is captured using a variety of gear types including purse seines, longlines, traps, handlines, bait boats and sport fishing. Since the 1990s, as the majority of the catch has been destined for farming purposes, the capture is mostly carried out by purse seine that allows the capture of live individuals. Minor quantities are still harvested using tuna traps. The major catch area for the Atlantic bluefin tuna is the Mediterranean Sea where 73 percent of the global catch is landed, followed by the Northeast Atlantic (15 percent). The majority of



the Mediterranean catch is destined for farming operations (Figure 8).

CAPTURE-BASED AQUACULTURE

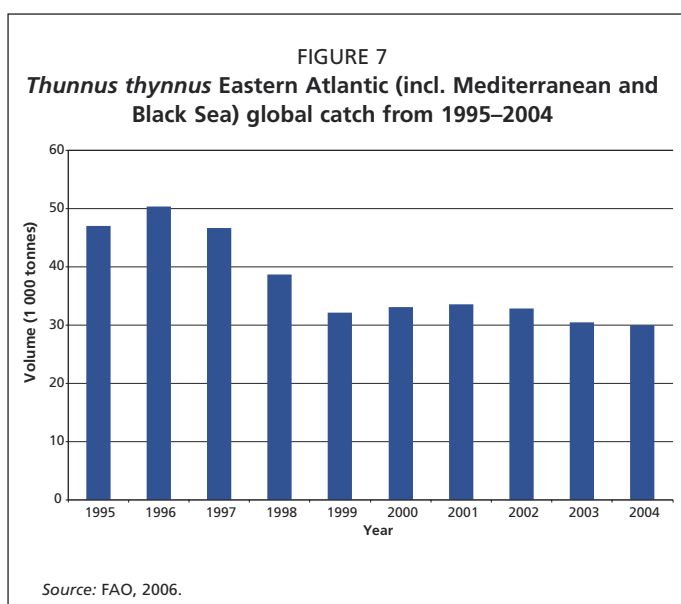
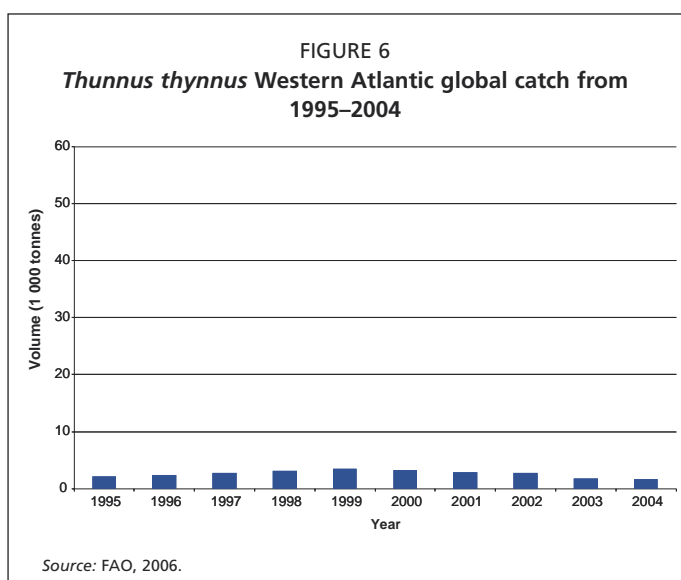
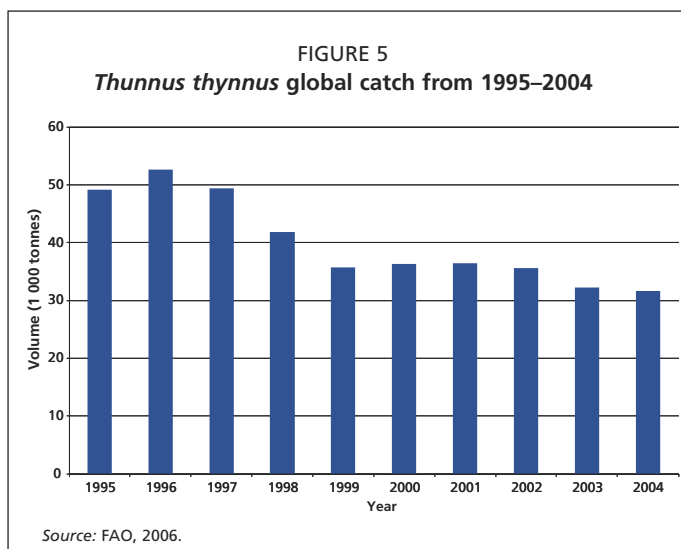
Thunnus thynnus is considered a capture-based aquaculture (CBA) species, as the farming activity is entirely based on the stocking of wild-caught individuals (Ottolenghi *et al.*, 2004). Scientists at Kinki University, Japan, achieved the completion of the life cycle of the Pacific bluefin tuna (*Thunnus orientalis*) under controlled conditions after 32 years (Sawada *et al.*, 2004). For the Northern bluefin tuna (*Thunnus thynnus*), research on reproduction and the rearing of juveniles has been carried out, however the closure of its life cycle has not been achieved on a commercial-scale. Driven by the Japanese market, capture-based aquaculture has developed significantly.

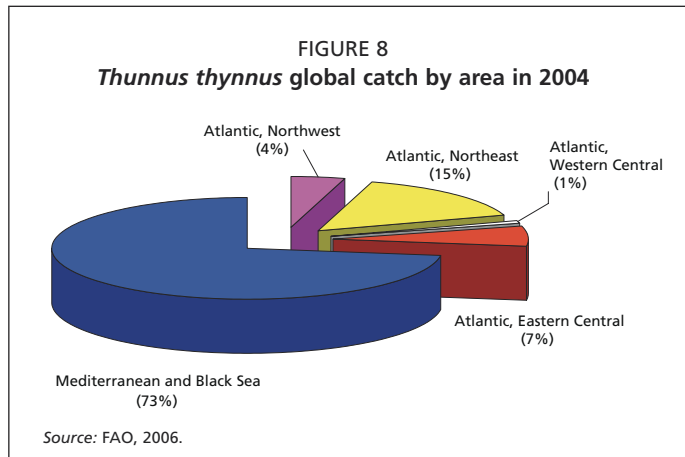
Fishing techniques, season and catching size

For farming purposes, wild tunas are caught at different life cycle stages, ranging from juveniles of less than 8 kilograms to large adult specimens. The capture system is the same for juveniles and adults, i.e. purse seines. This modern and widely used fishing technique basically creates a “purse” net to entrap the school (Figure 9).

In the Mediterranean juveniles are mainly caught in the Adriatic Sea by Italian and Croatian purse seines at the end of spring and in early summer. Juveniles at about 15 kg in weight were also caught around September-October in the Tyrrhenian Sea and during the harvest season in the Balearic Islands (now prohibited by EC Regulation No. 643/2007 of 11/06/2007). The main fishing period in the Mediterranean runs from May to July.

There is strong cooperation among the purse seine vessels, often supported by aerial search. Small aircrafts or even helicopters are used to detect bluefin tuna schools (a practice now





prohibited by ICCAT), however fish finders and sonar are largely used leaving little possibility for the fish to go undetected. A second capture system is the traditional tuna trap which are a fixed gear anchored to the sea bottom, aimed at intercepting tuna in their migration paths (Figure 10). While these are still in use in some countries (e.g. Italy), they are losing ground to the purse seiners, which are far more efficient in detecting and capturing the fish.



Aquaculture sites

Following the capture of wild bluefin tuna they are kept alive and carefully transferred to towing cages. The transfer action is a crucial activity as specimens may suffer severe stress that may lead to death. At present there is no efficient method to establish the fish biomass moving into the towing or farm cages making it rather difficult to determine the size and age composition of the fish. During the transfer process the fish are gently forced to move from the purse seine net to the towing cage usually by sewing the nets together (Figure 11). Divers often assist in this delicate operation and use underwater video cameras film as the film will eventually help in the discussions, often animated, between the fishermen and farmers in estimating the number and size of captured fish before a sale price is agreed. The industry considers the need to devise a better solution for determining the size and age composition of the captured fish destined for farming operation to be a priority. The lack of biometric information makes stock assessment and therefore, management and conservation of the bluefin tuna resource, rather difficult.



Once the tuna are all moved into the towing cages, tugboats are used to transport the fish from the fishing area to the on-growing or farm site (Figure 12). Towing speed does not usually exceed 1–1.5 knots in order to avoid excessive tuna mortality

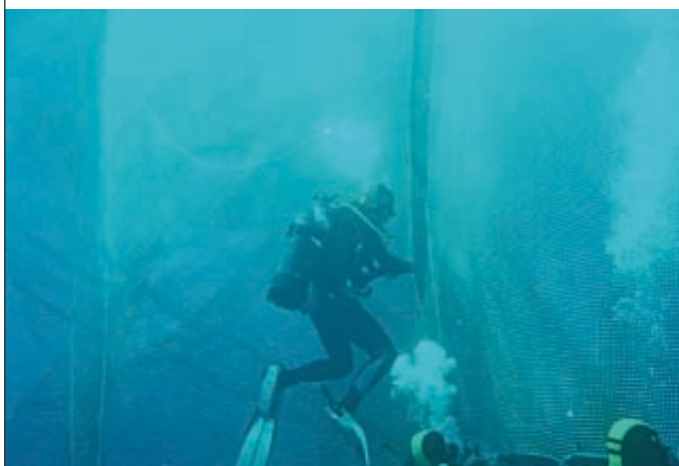
and to allow tuna to swim easily. However, such a low speed implies long transportation trips that may last days, weeks or even months which are further complicated by the need to adequately feed the confined fish. Mortality rates during transportation are usually quite low (1–2 percent) although there have been rare cases where all the fish have died.

In the Mediterranean, the companies engaged in this form of mariculture start stocking their tuna cages in late spring (May/June). This input season lasts for a couple of months (May/June or June/July), however, in the case of Croatia and Malta the season may extend to late summer (September). Mediterranean tuna farms largely use circular ring-type open-sea floating net cages, either built locally or purchased from several large equipment manufacturers (e.g. Bridgestone, Corelsa, Fusion Marine). The size of the cages varies from 30–90 m in diameter, with net depths commonly ranging from 15 to 20–30 m. The industry mainly uses cages with a 50 m diameter and net depths varying according to sea location. The larger cages (i.e. 90 m in diameter) are mainly used by the Spanish operators while those in Croatia prefer smaller ones in terms of net depth, i.e. 13 m (FAO, 2005). Generally the weight of the stocked tuna is between 150–200 kilograms, however Croatian operations generally start their farming with smaller specimens weighing around 8–25 kilograms, while countries like Italy, Malta and Spain may even stock giant tunas weighing as much as 600 kilograms.

In the Mediterranean, there are mainly two types of cages used, those for “farming” and those for “fattening”. The “farming” cages are designed to contain generally small tuna specimens for long periods of time often more than 20 months. Most countries in the region do not retain the fish for such long periods and usually only confine the tuna for periods of 1–7 months. The “fattening” season which may extend to February and generally not beyond December/January is closely linked to the market demand/opportunity. The fish may also be sold few days following capture as harvesting is often agreed beforehand between the producer and the fish trader.

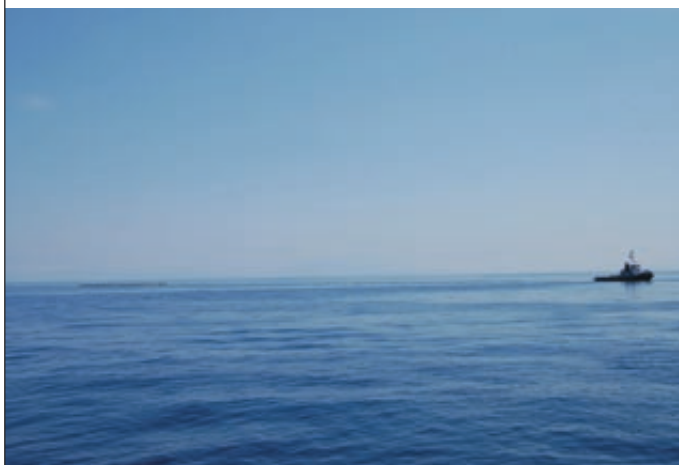
Many Mediterranean countries, including Portugal, are currently farming Atlantic bluefin tuna: Croatia, Cyprus, Greece, Italy, the Libyan Arab Jamahiriya, Malta, Morocco, Spain, Tunisia and Turkey. Farms obtain fish from local fishing fleets as well as from vessels bearing other flags (e.g. Malta and Cyprus often obtain their fish supply entirely from foreign vessels). Croatia, France, Italy and Turkey have the highest number of vessels used in tuna fishing (FAO, 2005).

FIGURE 11
Divers sewing nets for bluefin tuna transfer



COURTESY OF R. UGOLINI

FIGURE 12
Bluefin tuna tugboat



COURTESY OF R. UGOLINI

TABLE 1
Mediterranean countries farming
bluefin tuna in 2001 and in 2007

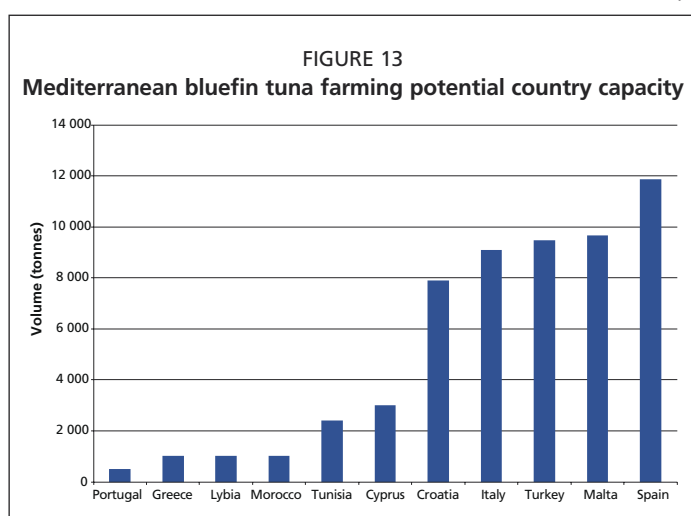
2001	2007
Spain	Spain
Croatia	Croatia
Malta	Malta
Italy	Italy
	Cyprus
	Turkey
	Libyan Arab Jamahiriya
	Tunisia
	Greece
	Morocco
	Portugal

Farm production/capacity

Tuna farming in the Mediterranean area started in Andalusia, Spain, in 1985 and expanded in 1996 to Croatia, in 2000 to Malta and in 2001 to Italy (FAO, 2005). As of 2007, eleven Mediterranean countries (including Portugal) were involved in bluefin tuna farming (Table 1).

The driving force behind this rapid expansion has been the Japanese market. As a result, farmed products are produced to coincide with the optimal fat content demanded by the “sushi” and “sashimi” markets. The total Mediterranean tuna production derived from the farming activities is difficult to calculate as the initial cage stocking information, i.e. biomass and fish size, is only a rough estimate and any weight gain

is generally kept confidential by the farmers. For all ICCAT Contracting Parties, bluefin tuna imports must be accompanied by the Bluefin Tuna Statistical Document (BTSD) and any country re-exporting the tuna must attach the original BTSD along with a re-export document. These documents are used to track the volume of farmed tuna exported to Japan which currently absorbs approximately 90 percent of total farmed tuna. In 2007 the potential capacity of all Mediterranean tuna farms authorized by ICCAT was 56 842 tonnes (Figure 13).



Farming mortality

Bluefin tuna mortality rates during the fattening/farming period have been recorded at around 2 percent; however some countries (e.g. Spain and the Libyan Arab Jamahiriya) have reported higher mortalities during the first month the tuna are in cages. This is generally due to the long towing trip which stresses and weakens the fish just before they are moved into the farming cages. Bluefin tuna show great adaptiveness in captivity and so far no specific diseases have been recorded, nevertheless high mortalities may occur due to adverse environmental conditions such as strong currents or elevated water turbidity. Preliminary investigations on the suitability of a selected farm site can prevent and minimize such risks.

Feed

Bluefin tuna are fed mainly with a mixed diet composed principally of a variety of small pelagic species including sardine (*Sardinella aurita*), pilchard (*Sardina pilchardus*), round sardinella, herring (*Clupea harengus*), mackerel (*Scomber japonicus*), bogue (*Boops boops*) and squid (*Illex* sp.). The proportion and volume of the feed varies among the different countries and from farm to farm, with feed composition also based on the availability of the species generally used. Mediterranean countries engaged in the tuna farming obtain bait fish from locally fished stocks or from imports stocks from outside the region, with the latter usually representing the largest proportion of the fish used by the industry

Bluefin tuna are generally fed 1–3 times a day depending on the farm and country, with a mixture of defrosted bait fish. In most countries a scuba diver remains in the cage during feeding, and signals to stop the feeding when tuna are satiated. When

the tuna are not fed *ad libitum* the daily feed input varies from 2–10 percent of the estimated tuna biomass and also depends on the water temperature and the fish size composition in the cage.

Without accurate initial length or weight measurements of the fish during cage farming, growth and feed conversion rates are only estimates. Under intensive farming conditions, growth, food intake and feed conversion rates have never been estimated accurately by farmers to avoid loosing the high value tuna as a result of the handling required to take such measurements (Aguado-Gimenez and Garcia-Garcia, 2005).

As for food intake, there is very little information available and it seems that overfeeding is a common practice among farmers. As the baitfish used varies in its nutritional qualities, it is not the quantity of baitfish supplied to the tuna that influence production, but the supply and quality of nutrients obtained from consuming them (Ottolenghi *et al.*, 2004). Feed conversion ratios (FCR) are generally high around 15–20:1 for large specimens and 10–15:1 for smaller fish. Bluefin tuna maintain an unusually high body temperature and their constant movement implies a high energy demand (Graham and Dickson, 2001). As a result only a small fraction (5 percent) of the total energy input is used for body growth (Korsmeyer and Dewars, 2001).

Several studies on farmed-raised tuna have demonstrated that the tuna are generally in good health and pose no health risks to consumers. Nonetheless, management control procedures for the tuna industry must be developed to prevent any risk and to provide a qualitative fish health assessment for food quality and safety.

Appropriate freezing procedures decrease health risks in baitfish-fed tuna; however several studies have shown deterioration in baitfish quality after a few days to one month, depending on whether the fish have been chilled or frozen (e.g. the fatty compounds in pilchards readily oxidises and therefore careful handling procedures may need to be adopted) (Munday *et al.*, 2003).

Considering the high volume of baitfish needed to feed tuna (2–10 percent daily of the BFT biomass farmed) there is an urgent need for research to develop artificial diets able to support a better feed conversion ratio and to ensure a better control over the quality of the fish produced (Ottolenghi *et al.*, 2004). The absence of formulated feed is of concern to the industry, particularly in view of the current high FCR when using baitfish. Scientific evidence indicates that fish weaned on a formulated diet that replicates normal nutritional intakes will perform considerably better than those fed on baitfish. Furthermore, the availability of artificial feed would partly eliminate or at least ease farm logistics in terms of sourcing, purchasing, transporting and storing the feed, as well as eliminate health risks associated with the use of raw fish.

At present only limited research studies are being carried out on artificial feeds at the farm level. Following the Australian efforts on Southern bluefin tuna (*Thunnus maccoyii*), encouraging results are being obtained in Mexico where the Pacific bluefin tuna (*Thunnus orientalis*) is cultured even though only a small percentage (<20 percent) of the tuna diet is made up of artificial feed (Figure 14). The main problems related to the use of the artificial feed have still to be overcome including high production costs and opposition/resistance from the Japanese market. Because the consumers mainly eat raw tuna meat, the taste of the flesh is important and does vary depending on the feeding strategy used by the farmers. For these reasons farmers prefer not to use pellets in order to avoid consumer rejection.



Environmental impact

At present, bluefin tuna capture-based aquaculture relies entirely on wild-caught seed, as the control of the full life cycle of the tuna at commercial-scale has yet to be achieved. This farming practice which is based on the removal of “seed” material from wild stocks clearly overlaps with the fisheries sector. In 2006 the SCRS has indicated that the spawning stock biomass (SSB) of the Atlantic bluefin tuna continues to decline while fishing mortality is increasing rapidly, particularly for large fish, and warned of a possible stock collapse. As a result in November 2006, ICCAT recommended establishing a multi-annual recovery plan (see section on Management).

It is well known that size and age composition of BFT destined for farming operations are not precisely determined and this affects the quality of available data for stock assessment. It is also apparent that the total allowable catch (TAC) set by ICCAT is not fully adhered to and is largely ineffective in controlling overall catch (ICCAT, 2006a). Therefore, there is a strong need to eliminate illegal fishing to ensure an efficient management of the fish stock.

As in all mariculture practices the grow-out component of BFT capture-based aquaculture poses concerns on the potential deterioration of the environment in the proximity of the farm site. Intensive fish farming generally generates a large amount of organic waste in the form of unconsumed feed, faecal and excretory matter. Such particulate matter can accumulate in the sediments below or close to the farm, causing an undesirable organic enrichment that may adversely affect the surrounding benthic community and, to a lesser extent, water quality (Ottolenghi *et al.*, 2004). In the case of BFT farming the fish are generally maintained in cages for short periods of time (often around 7 months, with the exception of Croatia) which allows a rapid recovery of the ecosystem.

Farm site selection, as for all other marine aquaculture practices, is of critical importance to ensure the operational sustainability of tuna farming. The selection of an inappropriate site may result in oxygen depletion in the bottom water layers that may lead to the development of anoxic conditions in the sediment and production of toxic gases such as hydrogen sulphide. These phenomena will adversely affect benthic organism (Ottolenghi *et al.*, 2004). Due to the biological nature of these large pelagic fish, farm sites need to be established in areas where there is a good circulation of well oxygenated water, a sufficient depth, etc. Careful site selection is therefore critical for successful and environmentally sustainable operation of tuna farms (Ottolenghi *et al.*, 2004).

As for feeding, the use of baitfish raises several concerns, including the relative impact of the harvest on the small pelagic resources, but also the high FCR (and consequently high discards) and the deterioration risk of the environmental as a result of the accumulation of uneaten bait fish on the sediment.

Socio-economic impacts

It is important to note that the tuna fattening industry has an economic impact in the Mediterranean area. There are huge financial investments, generally through major partnerships with Japanese companies, not only in the tuna farms but also in the capture fishery sector as a whole. This has, in some cases, resulted in modernization of entire fishing fleets, fitted with modern fish detection equipment, improved safety and crew comfort, and the use of new tug boats (e.g. Algeria built a whole new fleet). A modern 40–50 m length purse seine boat fitted with the latest equipment may cost around €3–4 million (US\$4.4–5.9 million). During the BFT catching season the daily rent for a tug boat may amount to €3 000 or US\$4 450 (excluding the cost of fuel as fish transfer trips may sometimes last for weeks). Furthermore, small airplanes are often used to detect fish, and some large operations had their own aircraft (now prohibited by EC Regulation No. 643/2007, 11/06/2007).

It is obvious that social benefits are often closely related to economic benefits, and the development of the BFT industry has created new job opportunities. At the same time, tuna capture-based aquaculture generates impacts and conflicts with other resource users such as the traditional tuna trap and longline operators. The activity of tug boats towing tuna cages disturbs the traditional longline fisheries in many countries (Italy, Malta, Tunisia) as well as reducing tuna catches. Bluefin tuna farmers in Croatia have caused problems and strong conflicts with tourism activities in the use of the coastal zone.

The BFT industry in the Mediterranean currently engages somewhere between 1 000–2 000 full-time workers, in addition to a considerable amount of casual labour during the farming season. The industry has also been characterised by the development of new skills, including teams of specialized divers, to properly handle harvesting operations, monitor fish mortality, moorings and inspection of cages, transfer of fish to the farm cages and appropriate killing procedures. Furthermore, tuna farms generally operate their own fleet of boats mainly for positioning the cages, bait transportation and feeding and for other routine farm activities.

Feeding constitutes one of the highest operating cost factors in tuna farms and one of the major concerns. Producers purchase bait fish from local fisheries but also through imports from other European Union (EU) countries and as far as the South and North American (mainly from the United States of America). The rising demand for small pelagic fish has had important effects on the market, e.g. sardine prices have doubled in 5 years (1998–2002) (De Mombrison and Guillaumie, 2003).

Market

Bluefin tuna prices have shown a decrease in the last 5 years. The cost/kg of BFT transferred live to the farms from the fishing sites is currently around €4 or US\$5.9 (2007 data) depending on the specimen size, while in 2000 and 2002 the price paid to the fishermen was €8–9.5 (US\$11.8–14). The value of BFT products sent to Japan has followed the same trend and the final income per kilogram of product exported sometimes barely cover farm expenses. In 2006 there was a significant shift in exports from fresh to frozen fish, also as a result of the high transportation costs. This has had several combined effects on market prices in Japan considering that this Asian country is almost the exclusive destination of farmed products. The high capacity to stock large amount of frozen tuna also allows traders to control the supply of the tuna into this lucrative market. In any case, it is evident that in 2006 the total fresh bluefin import trend into Japan have declined, lowering to 23 000 tonnes compared to 24 000 and 28 000 tonnes in 2005 and 2004, respectively (Table 2). According to data provided by the Globefish service of FAO the Japanese bluefin tuna business is worth ¥42 000 million or US\$354 million.

The final bluefin tuna products (mainly as sushi and sashimi) continue to show a positive trend in consumption, with prices depending on the quality of the individual fish specimen. A grading process determines the final destination of a bluefin tuna. This process, though apparently quick and easy to the uneducated eye, is a crucial factor for all the players in the trade network. By taking a thin core of flesh from the fish, the fisherman or wholesaler ascertains the fat and oil contents, appraises the colouring and outside appearance. In less than a minute and taking into consideration the market situation, the fish is tagged with a small slip of paper indicating its quality and final destination.

The main bluefin tuna consumption period in Japan falls during the many festivities in December that marks the end of the year. The whole tuna farming and fattening industry in the Mediterranean is based on such Japanese tradition. As the main tuna harvesting period is in the spring/summer months the fish are simply kept in cages for 6–7 months before they are harvested and exported to Japan to take advantage of the tuna price increase during such festivities.

TABLE 2
Fresh bluefin tuna imports into Japan (in tonnes)

Country	Year				
	2003	2004	2005	Jan-Nov 2005	Jan-Nov 2005
Mexico	1 896	3 849	4 097	3 318	2 359
Australia	2 769	2 839	2 343	2 343	1 693
Spain	2 537	2 693	2 277	1 757	1 643
Korea Rep.	2 579	667	1 479	1 464	1 001
Italy	366	346	314	304	254
Turkey	896	1 011	522	273	190
Croatia	226	123	240	101	162
Tunisia	221	144	212	180	106
Malta	647	449	180	122	97
Others	1 487	909	729	862	559
Total	13 624	13 030	12 393	10 724	8 064

Source: FAO Globefish.

Management

The introduction of tuna farming activities into the Mediterranean resulted in rapid changes in capture fisheries, with the purse seine fishery becoming the most important provider of live tuna to the farming sector. Catch limits imposed by ICCAT have been in place for the Eastern Atlantic and Mediterranean management units since 1998. In 2002, the Commission fixed the 2002–2006 TAC at 32 000 tonnes. At the Fifteenth ICCAT Special Meeting held in November 2006, the 2007 TAC was set at 29 500 tonnes an amount that would gradually decrease to 25 500 tonnes in 2010. This TAC reduction is a part of a general ICCAT multi-annual recovery plan for bluefin tuna and includes a series of control measures such as closed seasons, minimum size and regulation of caging operations (ICCAT, 2006). The plan aimed partly to respond to the Commission's Standing Committee on Research and Statistics 2006 stock assessment report that indicates that the BFT spawning stock biomass continues to decline while fishing mortality is rapidly increasing.

The SCRS nevertheless admits that the model used to assess the stock status has some limitations considering the increase uncertainties on current harvesting levels. In fact, as the main part of fish catch is destined for farming operations, the fish size and age composition is becoming more difficult to determine with the needed precision. Furthermore, it is believed that severe overfishing takes place and goes undetected hence reducing the efficiency of the TAC system in controlling overall tuna catches. It is clear that there is a strong component of illegal fishing and there are no effective policies against illegal, unregulated and unreported fishing (IUU) fully adopted and implemented by ICCAT's Member States.

The ICCAT attempt to protect the bluefin tuna spawning biomass and to reduce the juvenile catches by imposing a minimum size of 30 kilograms is an effort undermined, if not made useless, by the two exceptions included in the recommendation which allows fishing of 8 kilogram juveniles by (1) bait boats, trolling boats and pelagic trawlers in the Eastern Atlantic (mainly along the Spanish and French Atlantic coasts) for an amount of up to 2 950 tonnes in 2007 (about 368 750 individuals); and (2) boats that harvest in the Adriatic Sea for farming purposes. Furthermore, the ICCAT resolution also allows catching of individuals of <8 kilograms (and not <6.4 kg) for a total quantity not exceeding 200 tonnes. The situation is further complicated by the fact that several Mediterranean countries are currently not ICCAT members. The status of the Mediterranean bluefin tuna stock is in critical condition, and may face stock collapse unless dramatic actions take place at the regional level.

CONCLUSION

Over 90 percent of market demand for bluefin tuna comes from Japan, although important markets in Southeast Asia and the United States of America are emerging. There is an increasing global demand for seafood, a corresponding increase in demand for premium quality tuna for the sushi and sashimi market and a growing need to respond to the decline of most wild BFT fisheries worldwide. These are driving the development of reliable technologies for large-scale production of juvenile tuna, for both commercial food production and fisheries restocking. As these technologies improve, the economics of full cycle farming should also improve, and quite possibly result in changes in the market structure for hatchery-produced fish.

There would be benefits for fisheries, aquaculture and farm managers if BFT could be measured by underwater stereo-video without the trauma caused by capture and handling. In Australia, improved underwater measurements are currently being used with this system. The most significant disadvantage is the delay in the availability of information to farm managers and fisheries/aquaculture management agencies, due to the manual post-processing of video images (Harvey *et al.*, 2003). Similar studies are also being carried out in Italy and hopefully in the near future the quality of the biometric data will help to improve stock assessment which is the basis for an effective management of the resource.

In view of the extensive use of bait fish, the high feed conversion ratios and related farm management problems (e.g. purchasing, transporting, storage, and distribution of bait fish and environmental effects), the industry must intensify studies on artificial feed in order to mitigate the problems associated with the used of bait fish. In the meantime, however, there is a need to standardize control systems to ensure baitfish quality and avoid the introduction of potential pathogens. In order to ensure total transparency of the industry and traceability of traded tuna, farmers need to adopt and follow best farming practices throughout the production process.

Furthermore, urgent management actions are required to mitigate the impact of illegal fishing as it is estimated that 30 percent of total BFT catches derive from IUU fishing. These fishing activities must be controlled and eliminated and the industry must comply with the quotas agreed for the conservation of the wild stock. It is also recommended that the catch data from “recreational fishing” is recorded to curb illegal sport fishing of tuna.

The development of a specific bluefin tuna code of conduct should be shared by fishers, farmers and importers to ensure the implementation of all management regulations. This could also be a tool for the collection and reporting of bluefin tuna capture-based aquaculture data.

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Capture-based aquaculture of cod

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SUMMARY

The concept of capture-based aquaculture (CBA) of cod is not new, in fact Norwegian fishers delivered their first live cod for marketing in Grimsby (United Kingdom) in the early 1880s. Currently, there are concerns as the Norwegian quota for the wild capture of cod is at an all time low and the seasonal differences in catch quantity are large. In addition, consumers prefer fresh high quality products. To meet these challenges, capture-based aquaculture of cod has received increased attention.

Capture-based aquaculture of cod differs from the CBA of most other species in that it is not based on juvenile catches. Instead cod from traditional fisheries, i.e. cod which is more than 4 years old is kept alive for approximately 6–8 months prior to being slaughtered and marketed as a variety of fresh cod products. Cod CBA is marginal and accounts for only one percent of the total Norwegian cod production. However, its importance is expected to increase as the methods for catching and keeping the fish alive improve. Additionally, increased quality *per se* and biomass growth through fattening in aquaculture is expected to contribute to increased attention. In many respects, cod CBA is similar to that of the bluefin tuna, but is at present smaller and with less socio-economic effects.

The biology and migratory patterns of cod imply that it is only available for short periods of time in different areas along the coast; during spawning (February to April) and when it feeds on capelin (April to June). The traditional harvesting of wild cod is carried out over a short period of time and in limited areas where the fish is easily

accessible. This coastal catch, performed by small- and medium-sized vessels, is highly dependent on favourable weather conditions.

Even though technology has made it easier to locate and catch the fish even in difficult weather conditions far from the coast, there are still seasonal differences regarding both quantity and quality. The traditional seasonal pattern of fishing for cod creates significant challenges in product development and marketing for the processing industry. These variations in supply make it difficult to plan the production and choose production capacity. Additionally, in a market that demands predictability both in volume and quality, lucrative contracts may be lost because it is difficult to commit to long-term delivery of supplies. CBA is looked upon as a promising concept for meeting the two most important challenges in a growing fresh-seafood market by reducing the uncertainty of volume, quality, delivery and documentation.

Capturing cod in periods of the year where it is easily accessible and storing it in the sea lowers the uncertainty of supply and opens the door for commitments through long-term contracts with those parts of the market that demand stability in volume and quality. In addition, new research shows that allowing the fish to restore physiologically for 12 to 24 hours after capture, reduces the capillary blood in the muscle and therefore results in a whiter fillet.

Traditional, full cycle farming of cod as a third alternative to bringing cod to the market is emerging and the production in 2006 exceeded 10 000 tonnes live weight. This is similar to the salmon farming industry, while capture-based aquaculture is rooted in the traditional industry capture and processing of wild cod. The Norwegian strategy is to apply all three concepts, i.e. traditional catch, capture-based aquaculture and farming to meet the challenge of consistently supplying the market with high quality fresh products all year round.

In order to establish and encourage CBA of cod, several challenges and regulations must be met. A new legislation was launched in January 2006 that included criteria for vessels approved for live capture. The legislation's emphasis is on improved post-harvest animal welfare as the main tool to increase survival rates. As there is a strong link between welfare and quality, this strategy is likely to be adopted by the industry. Furthermore, the use of CBA is based on the development of different weaning and feeding regimes.

DESCRIPTION OF THE SPECIES AND ITS USE IN AQUACULTURE

Cod (*Gadus morhua* L.), the most important member of the Gadidae family, was formerly abundant on both sides of the Atlantic. Due to over fishing and environmental changes there has been a substantial reduction in stocks over the past decade. A fishing moratorium was introduced for the west Atlantic stocks (George Banks, Grand Banks, New Foundland – Nova Scotia, Canada) in the early 1990s and these stocks have not yet recovered. East Atlantic stocks are in better shape – ranging from South-East Greenland, Iceland, the Faroe Islands, the North Sea, the Baltic Sea, along the Norwegian coast and in the Barents Sea. The North East Atlantic cod stock in the Barents Sea is by far the largest and is managed within the limits of sustainable harvesting. It is mainly fish from this stock that are used for CBA in Norway. In total, cod harvest in the Atlantic has been reduced from 2 500 000 tonnes to less than 1 000 000 tonnes during the last 20 years.

Spawning, eggs, larvae and juveniles

Spawning takes place along the northern part of the Norwegian coast from February to May. The main area is Lofoten and the peak spawning period is in early April. From the age of six to seven years the cod recruit into the spawning part of the population. The females ovulate eggs every second day for five to six weeks. The spawning behaviour ends with male and female swimming belly to belly shedding eggs and sperm. The amount of eggs shed by the females equals approximately 500 000 eggs per kilograms

of bodyweight. The pelagic eggs hatch two to three weeks after spawning, depending on the temperature, and the larvae are 4–5 mm in length. Within a week the larvae start eating phyto- and zooplankton. The nauplii of the *Copepode* (*Calanus finmarchicus*) are the most important prey. At 10–12 mm the larvae go through metamorphosis and become juveniles. Transported by the coastal and Atlantic current, the juveniles become demersal at 5–15 cm in length. This takes place along the coast of Finnmark County and in the Barents Sea. The juvenile cod are called the “0-group” during their first year and the varying size of each year-class is mainly decided by the conditions during the first autumn.

In the late 1980s the artificial production of cod fingerlings was limited and the number available for the aquaculture industry was unpredictable (Olsen and Soldal, 1988). In 1988, 600 000 0-group juveniles were captured for aquaculture purposes. The juveniles were caught in shallow water (10–20 m) with a small-meshed seine net. Capture mortality was low (<1 percent) and the cod were easily weaned to a moist pellet. Unfortunately, the juveniles were contaminated with a bacterial disease (*Vibrio salmonicida*) and only a small portion of the fingerlings were grown to slaughter size (Jørgensen *et al.*, 1989). The capture of wild fingerling was not repeated in Norway, but similar experiments have been conducted in Iceland (2003–2005).

Capelin cod

At the age of 3–5 years, immature cod follow the capelin (*Mallotus villosus*) on their spawning migration from the Barents Sea to the coast of Finnmark County (see Figure 6). The cod feed on capelin for several weeks and are therefore referred to, during this period, as the “capelin cod”. The capelin cod are characterised by a very low terminal post-mortem pH, resulting in a very poor processing quality. Their loose muscle structure gives low yields in mechanical operations such as filleting or splitting. It is mainly this part of the North-East Arctic cod stock that is used for CBA. Capelin cod has shown great potential for growth and quality improvement due to controlled feeding in captivity.

DESCRIPTION OF THE FISHING ACTIVITY

The capture of cod for the purpose of keeping it live is a tradition in Norway. As early as the 1880s, Norwegian sailing vessels went to Iceland to fish for cod using long-lines. On the last two weeks of each trip, they stored the cod alive in a specially designed section of the vessel’s hull. Water was exchanged through perforations in the hull, but only when the vessel was moving. The reward, however, could be substantial as live cod could achieve a price one hundred times higher than salted cod. Capture-based aquaculture on cod varied in importance during the twentieth century, but it was not until the introduction of cod as an aquaculture species in the mid-1980s that it became important. Over the last three decades, cod CBA has reflected the available quotas for coastal vessels; low quotas leading to high activity and *vice versa* (see section on “Advantages of CBA of cod”).

Gear

Seine nets (such as Danish seine and Scottish seine) are by far the most important gear for cod CBA. Since 1990 major improvements have been made, both with regards to gear construction and how the fishery is performed. The pictures in Figure 1 show modifications to the cod-end where a canvas-lining reduces pressure on the fish and hence pressure damages (left). Each bag is emptied into a shallow bin where the cod is graded and sent below to the live-fish holding tanks (right).

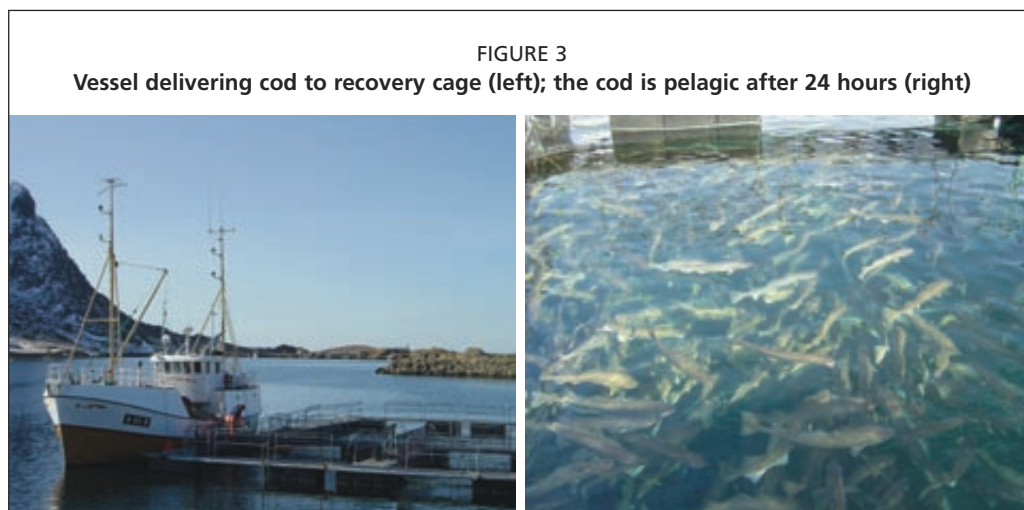
The gear is operated as in traditional fisheries, except for the final part of the haul-back where the hauling speed is reduced. This is done to reduce stress and allow for air from the gas-bladder to leave the cod. A final grading is performed following the



transfer to the holding tank, removing cod with residual gas. Normally all cod is alive when taken onboard. If the grading is done correctly, survival during transportation will be between 97 and 100 percent. Sixty percent of the cod from small coastal long-line vessels will survive capture and transport (Figure 2).

Figure 2 shows an automated line-hauler for coastal vessels which brings the fish onboard without the use of a gaffer (left). The fishers evaluate the fish and if the hook is swallowed or if the fish is damaged it is bled and gutted. If it has minor wounds it is transferred alive to the holding tank (right).





Cages and recovery

Upon delivery from the fishing vessel, the cod is lethargic and needs to restore itself physiologically as well as refill the gas bladder. Special cages with a flat and taut bottom are used for this purpose. Normally, 50 percent of the cod will move to the bottom of the cage where they will recover and the swimming bladder will heal. Within 24 hours most of the fish become pelagic and are ready for weaning (Figure 3).

Weaning, feeding and growth

As for most other wild fish species caught at an adult stage, the transition to captivity for the cod can be difficult. It is, however, a species with a wide range of behavioural assets which allow it to adapt to captivity within a few weeks. This is also reflected in the duration of the weaning time. If offered a wet-feed diet (herring, mackerel, capelin, sprat or squid) most of the fish will start eating four weeks after capture. On the other hand, if offered only a commercial dry-feed diet, practically all of the fish will refuse to eat. Recent trials to wean the cod with a semi-moist diet are encouraging and new methods are being developed, including vacuum-soaking of dry feed and the use of attractants and gustatory stimulation. There is an ongoing risk evaluation with regard to potential contamination of diseases through wet feed, in particular marine Viral Haemorrhagic Septicaemia (VHS).

Due to the fact that the cod prefer a diet based on the same food they eat in the wild and that there still are several challenges to be solved before the dry feed will suffice, CBA cod are mainly fed a diet of herring, mackerel, capelin, etc. These are wild-caught fish not suitable for human consumption, but intended for fishmeal production. All catch of these species is regulated with quotas. Depending on the state of the cod at capture, six to eight months of feeding will double the cod's weight, typically from 2.5 to 5 kilograms. The CBA and the farm-raised cod are slaughtered according to national aquaculture regulations.

LEGISLATION

According to the Norwegian authorities the term capture-based aquaculture embraces "the trade where fish are caught in the wild, stored for a certain time in a so called recovery/short-term storage phase and thereafter, as a main rule, fed to market-size under an aquaculture licence" (Fiskeridirektoratet and Mattilsynet, 2006).

The vast majority of Norwegian fish stocks, including cod, are subject to strong regulations in order to keep catch within precautionary limits. The Norwegian catch regulations are based on a core act, the salt water fisheries act, and several regulations pursuant to this, the most important being the regulations relating to marine fisheries.

Central elements of the regulations are total quotas, closed access, vessel and gear restrictions, vessel quotas and minimum fish size.

CBA has to comply with the full set of regulations, and in addition some specific regulations. Hence, the catch of juveniles for on-growing is not allowed. The minimum size for cod is presently 47 cm, so CBA has to target fish of this size or larger. After a long debate amongst CBA fishers and the authorities, the present regulations for CBA came into force on 22 December 2005. The main objectives are to ensure fish welfare and provide stable conditions for fishers.

The new CBA-specific regulations have been developed to ensure that it is clear where participants are subject to provisions, and which provisions apply for the capture process, the recovery/short-term storage phase and the aquaculture phase. Consideration of fish welfare in all phases of CBA is fixed more clearly by these laws.

Farming of fish is regulated by the aquaculture act and its accompanying regulations. The main objective is to favour profitability and competitive advantages of the aquaculture industry within the boundaries of sustainable development. Central elements are limited licenses, environmental conditions and operational requirements. Not all CBA is subject to this regulatory framework. It applies when fish are fed or fish are transferred to a licensed farm site.

The following discussion provides an overview of the specific regulations concerning CBA, covering the process from catch to short-term storage and the legal implications of the aquaculture regulations for CBA.

Catch, transport, recovery and short-term storage phase

Provisions regarding capture, transport recovery and short-term storage are covered in the new regulations regarding the requirements for vessels fishing and transporting catches. The regulations also apply to all vessels fishing and transporting live fish of all species other than herring, mackerel, sprat, eel and saithe. However they do not apply to fishing and the transportation of shellfish, e.g. lobster, crawfish or molluscs.

The new regulations are in addition to standard regulations concerning vessels that participate in fisheries. All vessels and their equipment must be approved by the Norwegian Food Safety Authority before being allowed to participate in the catch of live cod. The requirements are aimed at ensuring fish welfare, and the most important points are:

- any gear or device on board the vessel shall not inflict any harm on the fish or unnecessary stress;
- hauling the fish on board must be done by either a water filled bag or vacuum pump;
- shallow grading bins on deck that are partially filled with water must be installed;
- fish must be transferred to holding tanks without harm or being exposed to free falling. It should be possible to automatically count the fish; and
- live fish holding tanks must have a flat and perforated bottom giving an even up-welling of water. Water circulation should be at least 0.5 litres of water per kilogram fish/minute.

Provisions concerning the catch of fish, where fish are to be held alive, placed in recovery or short-term storage, are stated in the regulation regarding fishing in the sea (Chapter XVII of the regulations). Here it is defined that operations shall always be conducted with regard to fish welfare and thus training is required. Some technical requirements are placed on the design and use of Danish seine for live capture and transportation time is limited to eight hours. For the storage and recovery of fish important points are:

- cages shall be placed at least 2.5 kilometres from the nearest aquaculture farm, and health control is required before delivery to a site with an aquaculture license;

- cages for recovery must have a flat bottom-panel. During recovery, cages must be supervised daily. Cages must not hold more fish than 50 kilograms/m² bottom-panel area; and
- after recovery, short-term storage cages must be regularly supervised. The fish have to be fed daily if stored for more than four weeks.

Quota control is essential in modern fisheries management. Provisions concerning vessel registration, weighing, obligation to fill landing and sales forms and quota settlement, are specified in the regulation of cod, haddock and saithe, north of 62 °N latitude and in the regulation concerning the duty of disclosure when landing and selling fish. Before fishing commences, vessels have to register at the Directorate of Fisheries' regional offices where they are given quotas in live weight. Quota deduction is based on a conversion of the final product weight, most often headed and gutted, to live weight using standard conversion rates. In order to maintain control of the amount fished, separate provisions have been made for CBA. The main points are:

- before landing the live fish a 12-hour notice should be given to the Fisherman's sales organization to enable it to check on the quota granted to the individual vessel;
- all fish must be weighed when landed. At first time landing of live fish (not including shellfish or molluscs) from fishing vessels to the recovery cages. The weight can be set by counting all the fish and only weighing a representative selection of fish to determine an average weight/individual;
- a landing form must be completed and returned to the authorities when the fish are transferred to the recovery cages. When the fish is sold a sales form must be completed;
- deduction from the vessels quota is based on the first landing document. Adjustments can be made if the weight has changed as a result of factors which the fishers are not in control of. Examples are spawning, digestion of nutrition or escapees from the cages (not due to lack of fisher control); and
- fish which die during storage are deducted from the vessels quota.

To maintain food safety, Norwegian authorities have standards for food items for human consumption. For fish, these are stated in the regulation of quality. Adjustments have been made to this regulation to accommodate CBA. Fish caught in the wild, which die during transportation from the fishing grounds to the recovery pens, can be sold for human consumption. This is based on traditional fisheries where all fish are dead before delivery and the fact that the fisher maintains the quality of this fish on board the vessel.

Aquaculture phase

When the fish have been transferred to holding cages, the owner can decide on the storing time. The fish can be stored short-term to exploit price variations or for quality enhancement. Long-term storage implies feeding to increase the available quantity.

Enterprises are subject to a specific regulation regarding the operation of their aquaculture installations. The provisions in this regulation are founded on the aquaculture act, the food production and food safety act and the animal welfare act. The main requirements are that operations must be technically, biologically and environmentally safe, as well as epidemiologically safe, i.e. fish shall be protected against unnecessary stress, pain and suffering. This involves trained workers, health control, accurate production journals and reporting to authorities.

Live cod are covered by the CBA regulations until weaning commences. After this, the aquaculture act comes into force with its more comprehensive and resource demanding provisions and requirements, as covered in detail below. During short-term storage, the owner is required to supervise the fish regularly. There are no provisions concerning slaughter.

The maximum time fish can be kept without feeding is set by the CBA regulations at four weeks. This restriction is much debated. Some wish to store live fish for a longer period of time without feeding, or to avoid the extra considerations imposed when entering the aquaculture legal framework. This could be the case in periods when prices for fresh cod are expected to increase, while the quantity of caught cod is expected to decrease. The authorities have so far argued that a short period is important due to precautionary considerations of fish welfare. The issue has been solved by allowing the fisherman to retain and feed the fish for up to 12 weeks without entering the aquaculture legislation. However, the limit is under revision and the authorities have signalled an increase of up to 12 weeks.

When fish are fed, the aquaculture act comes into force, and several extra considerations need to be made. The aquaculture regulations require enterprises to hold a valid licence for farming marine species; the regulation concerning the licence for aquaculture for species other than Atlantic salmon, trout and rainbow trout of 22 December 2004.

Unlike short-term storage without feeding, aquaculture operations must adhere to extensive regulations concerning slaughter; i.e. proper sedation is required and slaughter has to take place at a licensed plant. New legislation and slaughtering procedures of aquaculture organisms were launched on 1 January 2007 to improve welfare and quality of farmed fish. This includes a ban on the use of carbon dioxide for sedation (effective from Summer 2009).

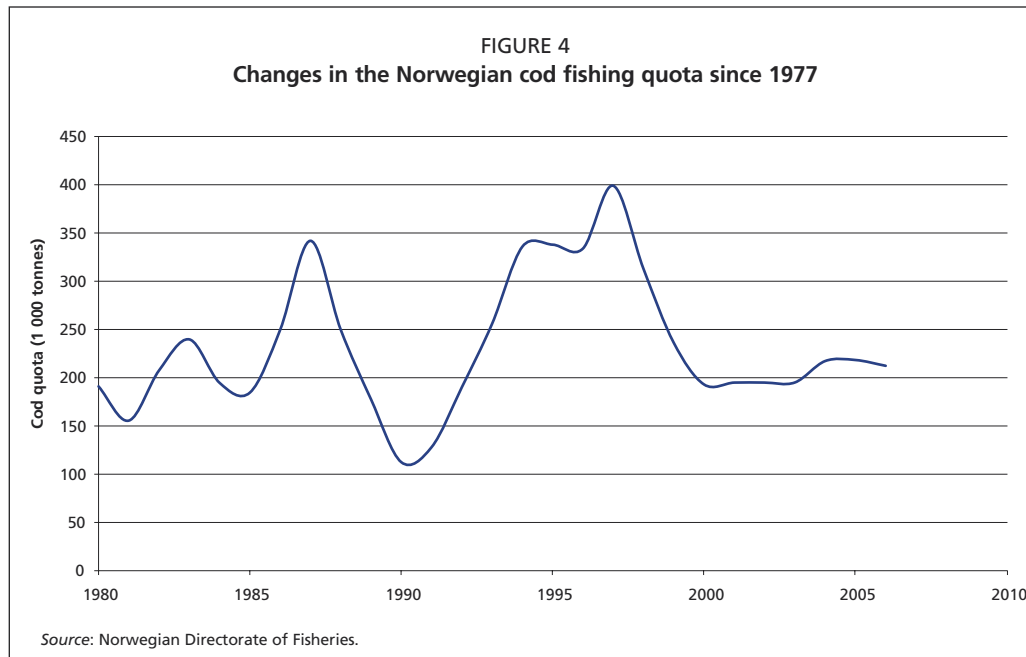
Marine aquaculture licences are given to a specific company for farming of specific species at appointed sites and life stages. Given that the application satisfies a set of conditions, licences are granted. These conditions are defined by various sector laws: the harbour act, the food production and food safety act and the pollution control act. In addition to the regular fish farming licences, a special licence for CBA has been designed. This allows a smaller quantity of live cod to be stored; it requires less information to be collected for the application, is less costly and involves less bureaucracy.

ADVANTAGES OF CBA OF COD

Harvesting of cod has always been important for people inhabiting the Norwegian coast. It is the most valuable species for the industry in terms of both revenues and employment. The traditional way of organizing the industry has been through fishing licences for professional fishermen that catch the cod in winter close to the coastal areas in the northern part of the country. Due to the seasonal migration pattern of cod, i.e. mature fish migrating to their spawning areas or immature cod hunting capelin, harvesting in winter is an efficient fishery, with high catch per unit effort (CPUE) and low costs. Improvements in technology related to finding and catching cod have made it necessary to implement management regimes to ensure sustainable harvest levels. This process has led to fewer vessels and fishers. In order to cope, fishers have had to devise ways to increase the volume of catch or to add value to a fixed quota. In the search for this, CBA has received attention particularly in recent years.

Capture-based aquaculture of cod is based on competitive advantages in relation to traditional capture harvesting. These advantages rest on major weaknesses in the traditional way of harvesting cod. First, the cod quota has recently been set at a historically low level, meaning there is a lack of supply on several markets. Second, the short fishing season opens the possibility of receiving a price premium if sellers are able to supply the markets with cod out of season. Third, if you are able to grow wild fish in cages, the volume increases accordingly to a sustainable level of catch. Last, consumers prefer fresh and high quality cod and CBA is well suited to serve such market preferences.

A closer look at how the traditional catch of cod has developed reveals several aspects that point in the direction of increased cod CBA. As stated earlier, the interest

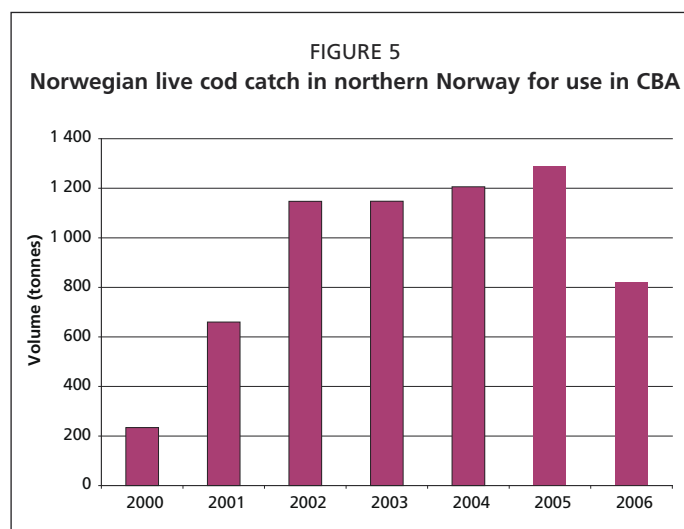


for catching live cod is closely related to the size of the cod quota. In periods with low quotas the interest is high and *vice versa*. Figure 4 presents the Norwegian cod quota for the last three decades. Not surprisingly, major technological breakthroughs related to CBA were achieved during the period 1988 to 1995. However, fishers lost their interest in CBA in the mid-1990s when the quota increased again. As shown in Figure 4 the quota fell to a low level in 1998, opening new boundaries for cod CBA.

During the period 1990 to 1994 the annual catch of cod for farming was around 1 000 tonnes. The development of knowledge and technology in the 1990s laid a good foundation for the new interest (Midling, 1994; Midling, Beltestad and Isaksen, 1996; Akse and Midling, 1997; Midling, Beltestad and Isaksen, 1997; Midling *et al.*, 2005). Figure 5 shows the annual catch for farming since 2000 in the northern part of Norway which is the most important region for cod CBA. In 2005 the quantity of cod delivered live at the national level reached a peak of approximately 1 500 tonnes.

As can be seen from Figure 5 there was a considerable drop in live catches from 2005 to 2006. This is not explained by a drop in catch quota, but mainly by market price changes. The price for cod caught live was in 2004 and 2005 almost 45 percent higher than the price for ordinary wild-caught cod. Although the fishers experienced a rise in cod prices in 2006, the price premium for live-caught cod dropped to only 30 percent. The price premium fishers receive for catching live cod thus also impacts on the development of cod CBA and fishers use CBA as an alternative market outlet, as volumes to this outlet are sensitive to price changes in the traditional value system.

The Norwegian Government expects that the CBA industry will contribute to considerable added value from the cod. They are planning a production level of 30 000 tonnes of live cod in the



near future, although the current catch level is far below this goal. In the summer of 2007 the Government announced that it will provide a quota premium for each kilogram of live caught cod. This was put into force for 2008, and only 80 percent of the live fish weight was deducted from vessel quota. A marked rise in landings indicate that this is an effective instrument. Furthermore, it will financially support investments needed to improve vessels and to establish infrastructure for storing live cod.

Seasonal pattern

Live cod is mainly caught by Danish seiners along the coast of Finnmark, Lofoten and Vesteraalen off the Norwegian coast from April to June, with the largest volumes caught in May. These areas are important fishing grounds in northern Norway and yield substantial catch of cod and other species throughout the year, with Finnmark dominating the catch levels.

Figure 6 marks the main cod fishing grounds and spawning areas in Norway along with the five CBA farms that buy live cod (regular full cycle cod farms are not marked).

Another interesting dimension of the live capture of cod is the seasonal pattern as shown in Figure 7. It seems obvious that the fishers find the period from April to July the most desirable month to carry out fishing for live cod. The traditional fisheries for cod have, as shown in Figure 7, a rather different pattern. One reason for this might be that vessels give priority to the traditional cod fishing season which runs from January to April. They then participate in the live catch when there is more time available for this activity.

The fishing grounds close to Finnmark have a dominant position in the fishery. This is due to the time of year live when the catch of cod is carried out, the migratory pattern of cod and its accessibility. The cod caught are mainly capelin cod, some smaller cod from the coastal stock of the *Gadus morhua* species or spent cod on its way back to the Barents Sea. The catch of live cod is carried out in a region and at a time of year

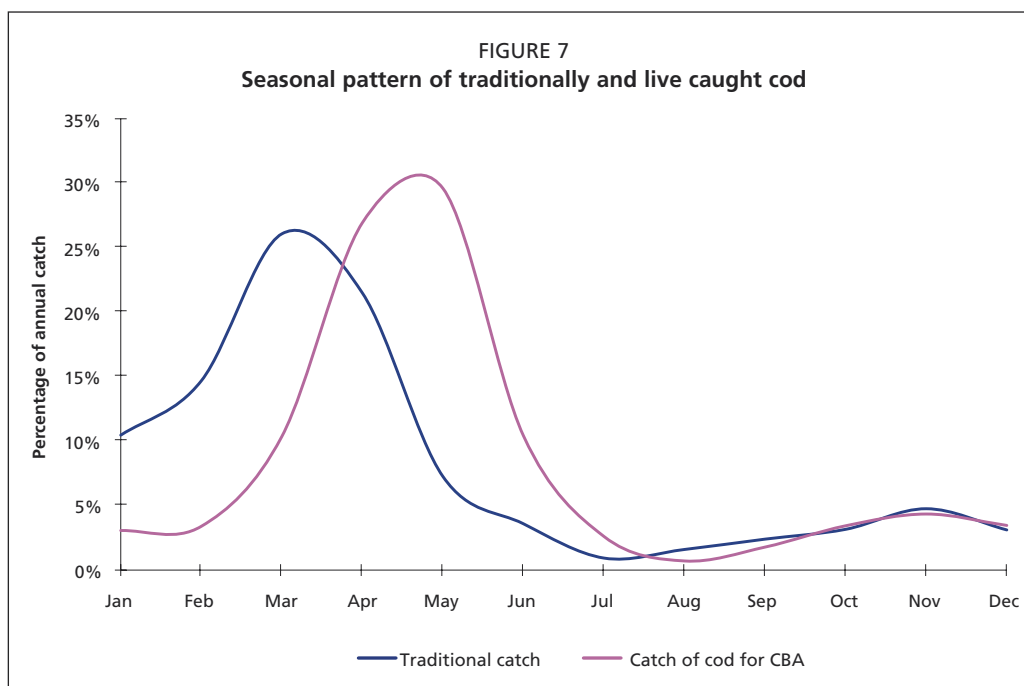
when the cod is close to shore. This time of year coincides with calmer weather and better conditions for both harvest activities and live transport.



Adding value or minimizing costs?

Detailed studies of the industry structure related to CBA reveal that over the years there has been substantial structural change in the wild cod fleet. During the period 2000 to 2006, there have been nearly 200 different vessels delivering live cod. Of these, 140 vessels delivered less than 5 tonnes during the 6 year period, and only 14 delivered more than 100 tonnes of cod. Only 15 vessels delivered cod every year in the same period. Even among these vessels, only a marginal volume of their total cod quota is caught live.

Of the 7 000 tonnes live caught cod during the period from 2000 to 2006 almost 6 000 tonnes were caught by Danish seine. The number of years each vessel delivered live cod, combined with



the distribution of catch between the vessels, indicates that there are almost 20 Danish seine vessels that maintain continuity in the cod fisheries. These vessels have several similarities; they are very flexible regarding their fishing gear; they switch easily between purse seine and Danish seine; and many are set up to transport the live fish from the fishing ground to the recovery cages in bulk. Furthermore, these vessels do not have licences for fishing other species such as herring and mackerel thus allowing them to concentrate on cod fishing. Another important characteristic for these vessels is that they only catch part of their cod quota live. In other words, they take advantage of the possibility to add value to their cod quota by delivering it live because they have the time and are properly equipped.

The reasons that so many vessels find it interesting to keep up with the live cod fishery, but not make a permanent commitment are many and complex. Empirical findings indicate that the size of the cod quota, quota portfolio, price premium, risk and legislation are important factors that influence the decision of whether or not to continue with live catch. Another problem is logistics. High fuel prices and long transport to the acclimatization cage sites are reasons for not engaging in live catch. The development of transportable storage cages or other infrastructure solutions, such as acclimatization cages close to the fishing grounds, are necessary. Additionally, CPUE and costs are important factors to consider when choosing a harvesting strategy that optimizes the profit of a fixed cod quota.

The initial cost to equip the vessel for live catch is estimated by the Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (SINTEF) to be from €67 000 to €100 000 depending on the size of the vessel (Aasjord and Hanssen, 2006). If it becomes necessary to upgrade to a more powerful engine the cost increases by €40 000. In any event, the issue of lower capacity for catch, loading and transportation of live fish will always have to be considered when planning the future use strategy of the vessel.

The fishers carrying out the live cod fishery for the CBA industry are also important contributors to traditional fisheries. As a result, there will always be a trade off between how, when and what will receive priority. Over the years, the average price of live cod has been 30–40 percent higher than the price of traditionally caught cod. However, due to the fact that the live cod fishery is more time consuming and vulnerable to weather conditions, each year fishers have a difficult choice as to whether or not they should

engage in the CBA fisheries. As the peak season for traditional cod fisheries is earlier than the optimal period for catching and storing live cod fishers must decide at the beginning of the year whether they should leave some of their cod quota in the hope that the increased price of live cod will outweigh the extra time and effort spent on catching them.

Optimizing profit includes a complex evaluation of how these factors will develop. Empirical studies indicate that they change rapidly and in directions difficult to predict. Mapping of important factors – with impacts on what strategy to choose – reveal that the vessels chose different variations of volumes of wild-caught cod, as shown in Figure 5.

Market positioning

Although there is minimal research on the organizational structures of the CBA industry its organizational pattern is built on the same basis as the traditional cod fisheries. The ownership of the fish changes the moment it transfers physically from the vessel to the buyer. The start up cost of participating in the CBA seems to be shared between the participants. The owner of the vessel invests in the equipment necessary to carry out the fisheries, the transport of live fish and the handling of the fish on board the vessel. The buyer, i.e. the shore-based industry, invests in the necessary fattening cages and equipment for slaughtering and production.

The industrial buyer

The competitive situation in the Norwegian industry calls for an increased interest in CBA from an industrial point of view. Recent years have brought about an increase in consumption of fresh seafood products and a higher demand for stability in supply. Supermarket chains want to be able to offer the same product portfolio all year round. It is impossible for the Norwegian industry to meet such obligations by depending only on the supply of wild cod due to the migratory pattern of this fish species.

The processing industry buying live cod is mainly located in Finnmark, even though many of the vessels deliver to the Lofoten and Vesteraalen areas. This is no surprise considering that the main fisheries are carried out off the coast of Finnmark. For these companies it is evident that the farming and production of live cod is only a supplement for their traditional production. The companies commonly have a portfolio of products which changes by season and with access to raw material. This access can be better controlled by the company when they store the cod live, compared to depending only on traditionally caught wild cod. Some cod fish farmers use CBA cod in addition to farming cod seed supplied from hatcheries.

Studies by Dreyer *et al.* (2006) indicate that the interest in buying live cod fluctuates from year to year. In the period from 2000 to 2006, there have been 33 different buyers involved. Of these, 27 tried out the concept for one or two years before deciding not to continue. Four companies purchased more than 500 tonnes (cumulative) of live cod throughout the aforementioned period, and only 2 companies continued to buy the fish on a regular basis. Occasionally, as much as half the total catch of live cod is bought by one company, however never the same company every year. This has caused a problem for the stable part of the industry due to the numerous companies testing the live cod market. This causes instability in access to live cod and also forces prices to rise. The decision to withdraw from this supply market is, however, not only due to negative experiences from the capture-based concept. There has also been a great deal of turbulence in general in the industry during this period.

Marketing strategy

Marketing strategies have been developed for live-caught and farm-raised cod. One of the main competitive advantages of live cod is its freshness and constant quality. To

thoroughly take advantage of this benefit it is important to know if farm-raised cod maintains the quality level expected by a highly demanding fresh fish market.

A quality study carried out in 2001 showed significant variation between wild, CBA and full-cycle farmed cod (Johansen and Johnsen, 2002). In the same study a test was carried out amongst Norwegian chefs. Compared to farmed cod the CBA cod was given a low score on quality. Of 13 chefs, ten said that they would not consider buying CBA cod for their restaurant due to the soft texture and high degree of gaping. A second and more extensive study was carried out in 2002 by Heide *et al.* (2003). This time both the farmed and the CBA scored good results in terms of quality and, in contrast to the earlier study, the chefs were satisfied with the consistency of the CBA fish. The conclusion of this exercise indicates that CBA cod shows a substantial variation in quality, thus further research is needed to ensure that CBA cod maintains the quality level demanded by the market.

The development of CBA knowledge and marketing know-how are critical issues. It is necessary to find out *if* CBA cod have any competitive advantages and *how* these advantages can be fully exploited to improve profitability and add value to the available cod quota. Two marketing strategies can be considered: a) using the same channels as wild cod for distribution, sales and marketing of CBA cod; and b) differentiating CBA cod from the wild cod.

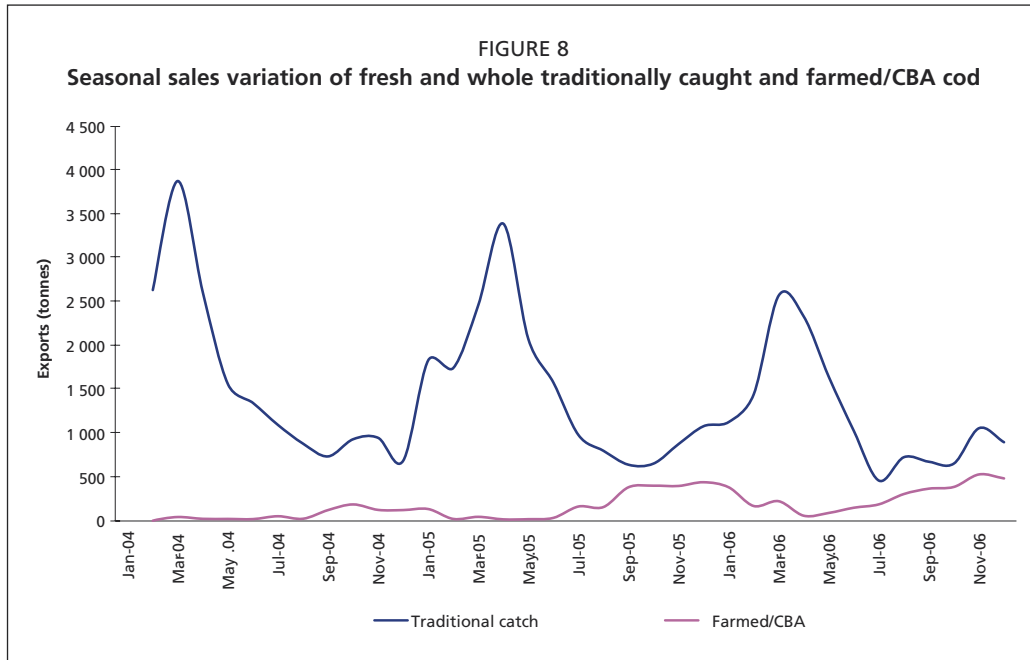
Branding regulations within the EU (Council Regulation [EC] 104/2000 of December 1999 on the common organization of the markets in fishery and aquaculture products) require that all fresh-farmed fish that are sold to consumers be branded as “farmed” and marketed as farmed fish. Furthermore, the Norwegian legislation (Aquaculture Act) specifies that wild-caught marine fish that are artificially fed shall be regarded as farmed fish and thus should follow the aquaculture legislation. Today, farmed cod is distributed and sold using the same channels as wild cod. In many ways this is a natural strategy considering the small amount of farmed cod that is available. The volume is far too small to be able to take advantage of the potential competitive advantages, such as supply stability to producers and consumers. However, the traditional full-cycle aquaculture of cod must be branded as “farmed”, and can be perceived as being different to wild cod. Furthermore, the CBA cod should be marketed as a separate product.

It has not yet been studied whether or not CBA cod has characteristics that make it possible to differentiate it from wild caught cod in other ways than by name only. However, research carried out on CBA Icelandic cod has shown that this cod has qualities which made consumers from different countries perceive that it was different from the Icelandic wild cod (Sveinsdóttir, 2006). In this study, CBA cod was perceived to be “meatier” than the wild cod and as much as 23 percent of the invited consumers preferred CBA cod. If further research of the Norwegian CBA cod reveals similar differences, there would be the potential to propose the CBA cod to consumers who prefer such qualities.

Tracing the cod in the market

Cod is mainly caught near the coast of Finnmark during spring time. It is difficult to trace CBA cod once it leaves the Norwegian producer. Interviews with participants in the CBA sector reveal how and where the cod ends up and eventually positioned in the market compared to traditional wild-caught cod. The main impression is that CBA cod is used as a supplement to the traditional production of fresh filets or exported as fresh whole fish.

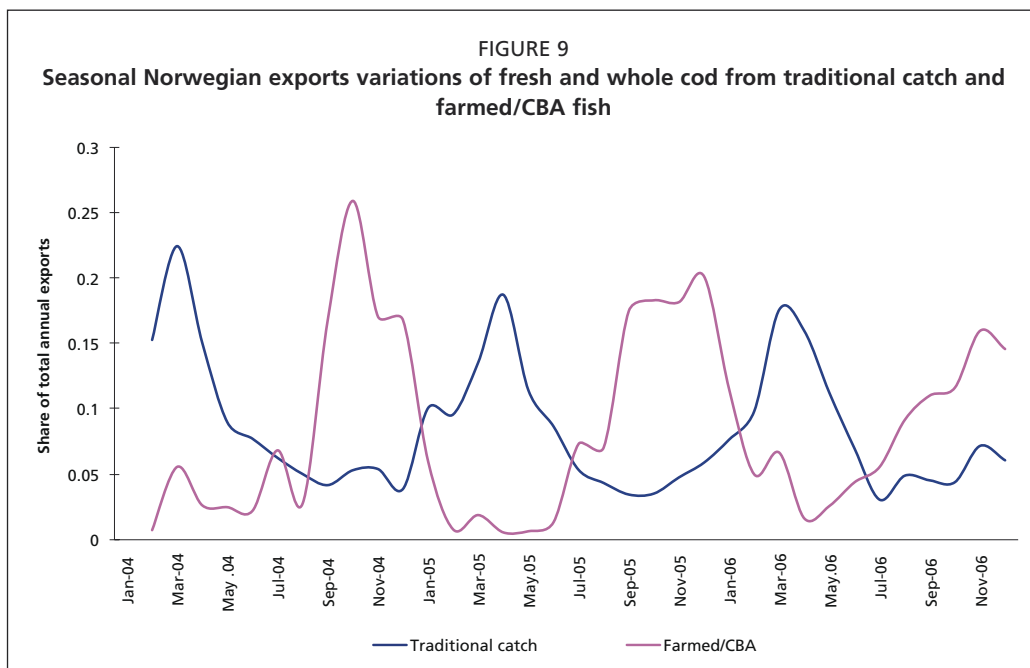
Figure 8 shows how the export of fresh whole cod evolved, on a monthly basis, from February 2004 to December 2006. The export is divided into traditionally caught cod and cod that are CBA or farmed. The figure shows that Norwegian export is dominated by traditionally caught cod. The quantity of traditionally caught cod, which is exported, coincides with the seasonal pattern of the traditional cod fisheries. The main quantity of cod is caught during the winter months.

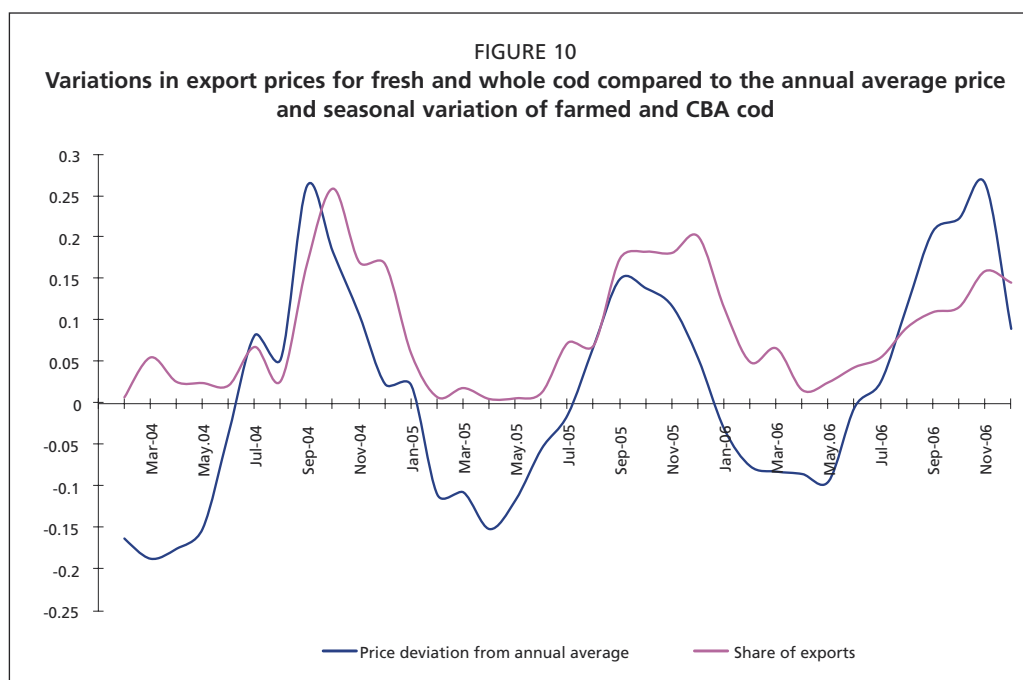


The industry based on CBA or farmed cod is expected to take advantage of the demand in the market for fresh cod in the months of the year when traditionally caught cod are scarce. Figure 9 shows the seasonal export of wild-caught cod and farmed/CBA cod.

The figure shows that farmed or CBA cod are placed on the market at a time of year when traditional cod fisheries are slow. As opposed to traditionally caught cod, the farmed or CBA cod are placed on the fresh fish market from September to December, supplementing the wild fisheries cod market, even though the quantity is less.

If the annual demand for fresh cod remains high as during the main exporting months, there is still room for a substantial increase in the quantity of farmed and CBA cod. How big an increase the market will accept is difficult to predict. The monthly amount of cod exported during the critical months lies between 3 000 and 4 000 tonnes of whole cod. If the market demand for fresh cod remains stable the whole year, the





total possible export of fresh cod would be around 40 000 tonnes. In 2004 and 2005 the total export of fresh cod was around 18 000 tonnes.

Figure 10 shows that the price for fresh cod varied substantially over the years. During the two years presented the price was above average in the autumn period and at its lowest during the first months of the year. Exported farmed or farm-raised cod are sold in the period of the year when the price premium is highest. The industry adjusts production so that it can place the product on the market at the best possible time to supplement the traditional fisheries. One of the main challenges the traditional industry is facing is supplying the market all year round.

SOCIAL AND ECONOMIC IMPACTS

Norway is a country with many small villages with 150–2 000 inhabitants. In the north and west of Norway, fisheries is often the main activity of the villages and a common social structure is the father working as a fishers, the mother working in the factory and the children taught to participate in these activities on weekends and school vacations – although this is changing. Due to smaller quotas for fish and technological improvements, there are fewer villages of these size and less recruits to most positions within fisheries. Fisheries have a reputation of being unpredictable and a low status occupation. A major challenge has been to adapt capacity to the sustainable management of crucial fish resources upon which many communities rely.

New technological breakthroughs related to CBA have opened new possibilities to add value to a sustainable cod fishery that can secure vulnerable jobs and improve profitability in an industry located in rural areas. In order to develop these possibilities several challenges have to be met. The extra costs related to this way of organising the value system have to be reduced and compared to the traditional harvesting model. Second, the consumers have to be willing to pay a higher price for the products produced by the capture-based industry.

Data indicates that the traditional wild harvesting cod outperforms cod CBA. However, statistics indicate that the two fisheries do not compete with each other – rather they compliment each other. As the actors in the two fisheries are the same, CBA has become a new option for people earning their livelihood from traditional cod harvesting. Exploiting the competitive advantages of CBA will improve profitability and secure vulnerable workplaces in this rural-based industry.

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Capture-based aquaculture of yellowtail

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SUMMARY

The 2004 production of cultured yellowtail (*Seriola* spp.) in Japan from 1 288 enterprises was 150 028 tonnes valued at ¥111.2 billion (US\$1.334 billion). Yellowtail mariculture has developed remarkably due to the abundant supply and low price of wild-caught juveniles (*Mojako*) and sardines used as the main fish feed of fishmeal component. Hatchery produced yellowtail seed are far more expensive. Other critical elements that supported the growth of yellowtail farming include the existence of abundant suitable culture sites along the Japanese coast and innovative technical developments.

The history of yellowtail culture in Japan began over 70 years ago. Before that, fishers cultured undersized fish in ponds and sold them when they reached marketable size. This utilization of bycatch (undersized fish) was accepted by the public, particularly as unmarketable fish were often used as fertilizer or livestock feed. Currently aquaculture production for many species exceeds that landed from capture fisheries.

Some commercial culture trials on amberjack have been undertaken in Taiwan Province of China, Mexico and Vietnam, but no successes have been achieved with raising yellowtail. The main constraints include diseases and low production costs in tropical areas. In contrast, the culture of *Seriola* spp. is promising due to their strong vitality and rapid growth, and may well expand at the global level through hatchery-produced juveniles.

DESCRIPTION OF THE SPECIES AND ITS USE IN AQUACULTURE

Life cycle and geographical distribution

The genus *Seriola* or yellowtail, a highly active fish belonging to the Carangidae family, is found in the Atlantic, Indian and Pacific oceans, with most species occurring in tropical and subtropical waters. A few species have global distribution (such as the amberjack, *Seriola dummerili*, and the Pacific yellowtail, *Seriola rivoliana*) while others, such as the Japanese yellowtail, *Seriola quinqueradiata*, have a more limited regional distribution. Currently approximately 12 species of *Seriola* that have been described.

These fish are typically streamlined, elongated and laterally compressed. Larger members of the genus which are commonly cultured (i.e. the gold-striped amberjack, *Seriola lalandi*, and *Seriola dummerili*) may reach 200 cm in length and weigh up to 50–60 kilograms. *Seriola* spp. typically inhabit deep open waters often adjacent to

TABLE 1
***Seriola* species cultured in Japan**

English name	Yellowtail	Amberjack or great amberjack	Gold-striped amberjack or yellowtail
Japanese name	Buri, Hamachi, Mojako	Kanpachi, Akahara	Hiramasa
Scientific name	<i>Seriola quinqueradiata</i>	<i>Seriola dumerili</i>	<i>Seriola lalandi</i> or <i>Seriola aureovittata</i>
Market size	up to 6 kg for fillet 3.5–4.5 kg for sashimi	3.5–5.5 kg for sashimi	up to 4 kg for fillet and sashimi
Price (¥/kg)	600–900 to producer 1 200–2 500 to consumer	800–1 300 to producer 1 500–3 000 to consumer	700–1 200 to producer 1 500–3 000 to consumer
Maximum size	up to 15 kg	up to 70 kg	up to 50 kg
Juvenile cultured (as of 1997)	53 303 × 10 ³	17 200 × 10 ³	2 500 × 10 ³
Geographical distribution	Japan, Korea, China	Asia-Pacific and Mediterranean Sea	Japan, China, Mexico
Seed supply	Wild, Artificial propagation	Wild (also imported from China and Viet Nam)	Wild juveniles of about 700 g caught around the Goto Islands

Source: Nisshin Feed Co. Ltd.

offshore islands or coastal areas where they may also be present in shallower areas. Their prey includes a variety of fish, squid and a number of crustacean species.

In Japan, yellowtail spawn offshore from southern Kyushu to Chugoku off the Sea of Japan and then migrate north to Hokkaido where they reach sexual maturity in 3–5 years. Following this they migrate south again to spawn (Abe and Homma, 1997). Throughout the season, various sizes of yellowtail can be caught in different parts of Japan where special names are given to fish of different size (Suehiro and Abe, 1994). Migratory populations are differentiated by their growth rate and nutritional status (Abe, 1987). All juveniles weighing less than 50 g are called *Mojako*. Cultured yellowtail weighing <5 kg are called *Hamachi*, and those heavier than 5 kilograms are called known as *cultured-Buri* which are distinguished from the *wild-Buri* (Abe, 1986). All cultured Carangidae in Japan have different characteristics and require different culture methods as shown in Table 1.

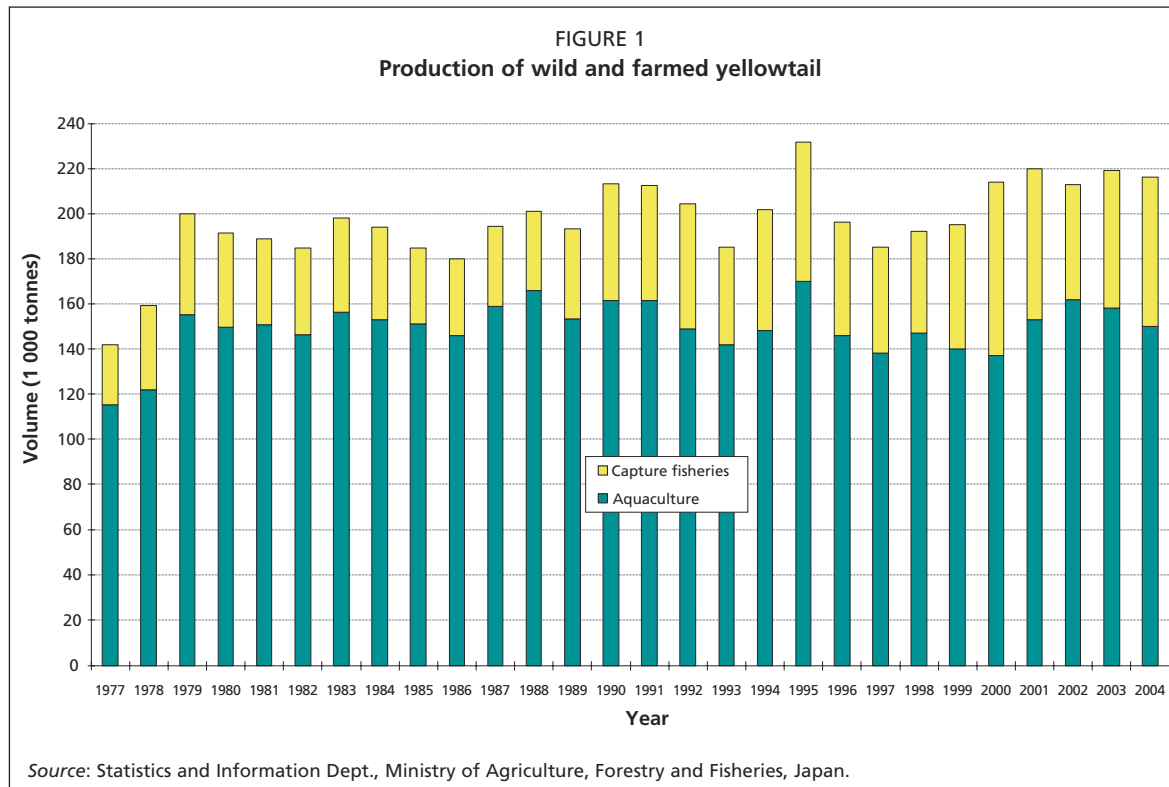
Amberjack aquaculture has developed rapidly and the species rivals yellowtail in popularity. The amberjack meat maintains its brilliant colour and firm texture longer than that of the yellowtail and, due to its superior quality, it usually attains a much higher market price compared to cultured red seabream (*Pagrus major*), which is a highly valued fish species in Japan. Amberjack is distributed throughout the world and is a popular game fish in Hawaii (United States of America), Australia and in the Mediterranean Sea. This species grows faster and has a better feed efficiency than yellowtail at water temperatures higher than 17 °C.

Capture fishery

Yellowtails of various sizes are harvested from many fishery grounds along the Japanese coast using several kinds of fishing techniques. In 1995, capture fisheries of yellowtail yielded around 61 666 tonnes, and aquaculture production yielded 170 312 tonnes, totalling 231 978 tonnes (Figure 1). In 2004, capture fishery landed 66 345 tonnes using different fishing gear including set nets (21 786 tonnes), round haul nets (18 876 tonnes), purse seines (11 581 tonnes), gillnets (6 006 tonnes) and other fishing techniques (8 096 tonnes). At present, wild yellowtail capture fishery remains stable whilst yellowtail aquaculture continues to increase.

Collection and culture of wild seed

After the wild *Mojako* juveniles are harvested, measured and the numbers recorded by the cooperatives, they are weaned on artificial feed and weak specimens discarded. As young yellowtail and related species are sensitive to food deprivation, cannibalism

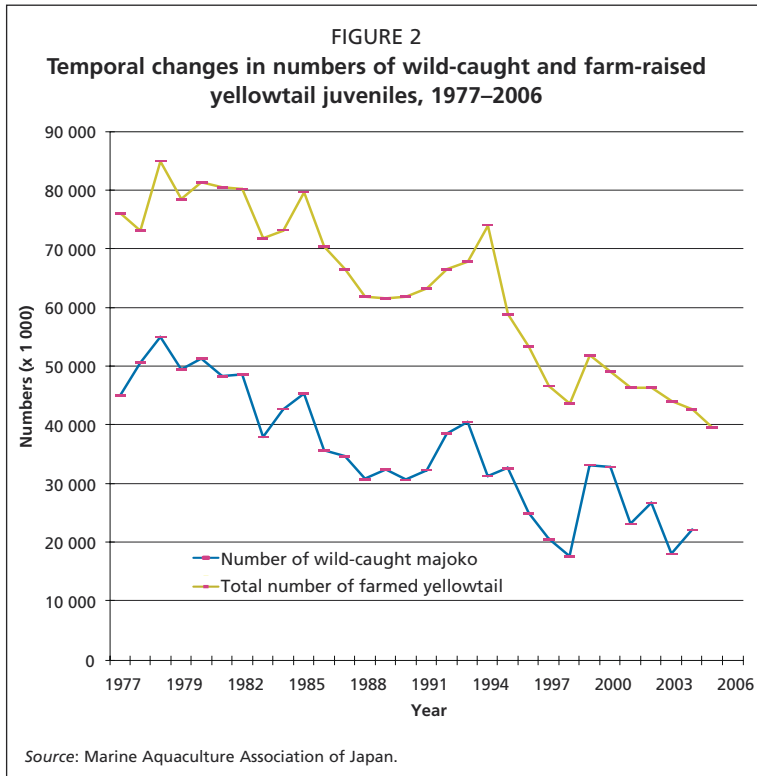


may occur, particularly if the fish are kept in the holding tanks for long periods. Furthermore, if the young fish are not fed for more than three days they will usually fail to adapt to the artificial feeds.

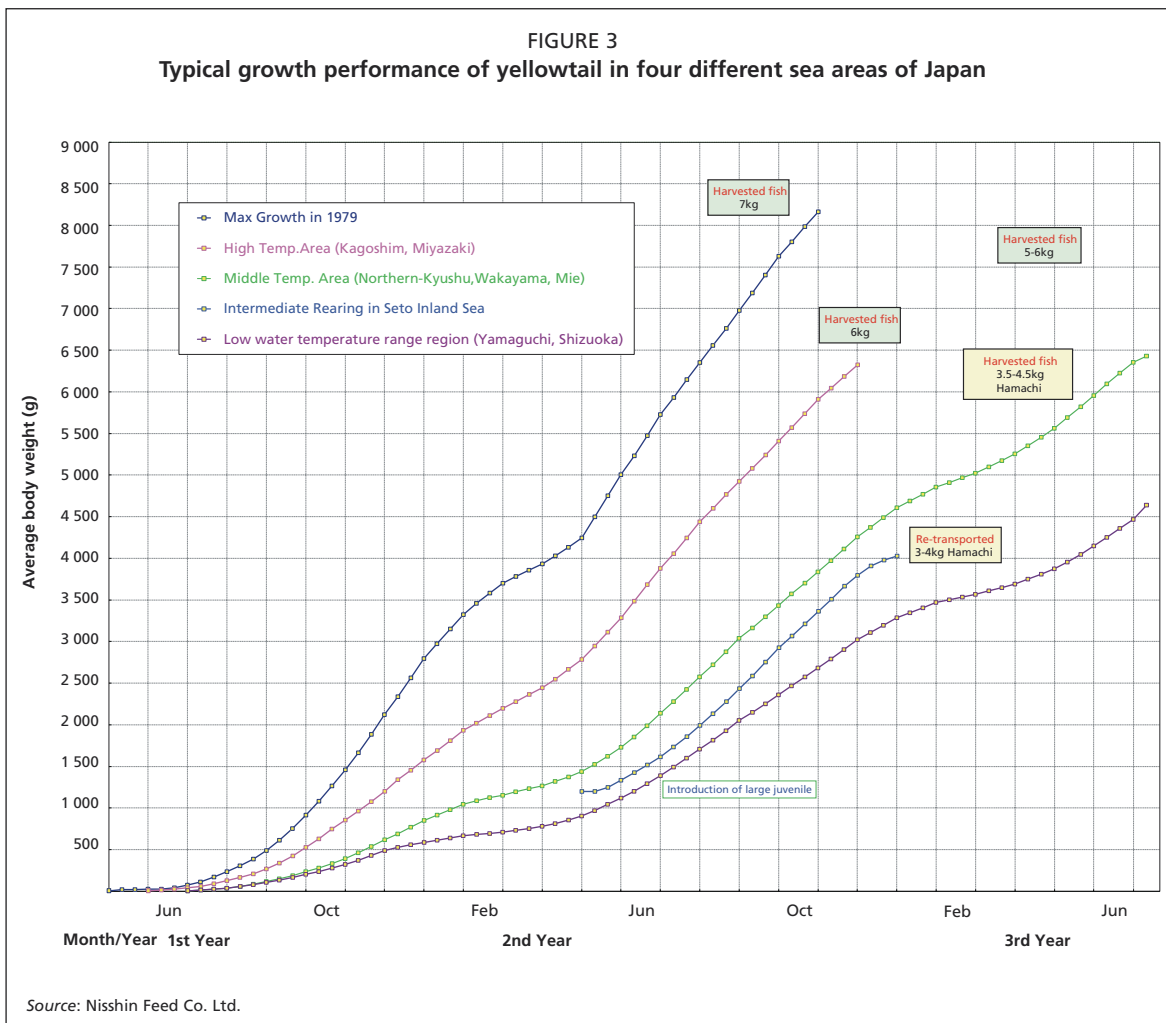
In 1998, the Fisheries Agency of Japan imposed regulations limiting the number of *Mojako* that can be caught annually for use in aquaculture to approximately 25 million in order to ensure the sustainability of the fishery and to protect the resource. The Marine Aquaculture Association of Japan determines the fishing allocations made to each prefecture, while each prefecture decides on the fishing season and distribution of the fishing permits to the local Federation of Fisheries Cooperatives. In 1970, the number of *Mojako* caught was over 100 million individuals, however, over the past 30 years the harvest has fluctuated between 30 to 100 million, and dropped to 25 million in 1997 (Figure 2). Fish farmers were, however, able to maintain a total production level of about 150 000 tonnes despite the decrease. The highest production level was achieved in 1995 with 170 000 tonnes produced. More recently the domestic supply of *Mojako* showed a significant decrease, and a few million were imported from the Republic of Korea. Juvenile amberjack (*Seriola dummerili*) are usually caught with *Mojako* and at one time the two species were cultured together. However, due to the parasitic worm, *Benedinia*, often present on the amberjack, farmers prefer to raise the two species separately.

The current price of amberjack juveniles ranges from ¥500–1 500 (US\$4.8–14.3) for fish weighing between 50–600 g. The high price facilitated the commercial production of hatchery-reared juveniles. Japan has imported wild-caught juveniles from China and Viet Nam via China Hong Kong Special Administrative Region (SAR) since 1986.

Farmers prefer to use wild-caught seed over hatchery-produced seed as the latter are generally more expensive and are usually too small for successful rearing. In 2003, the Fisheries Agency of Japan succeeded in spawning and producing yellowtail seed larger than wild *Mojako* by controlling the water temperature and the photoperiod cycle of the broodstock. Unfortunately, however, the hatchery-produced seed had a high percentage of body deformity and mass seed production has not achieved mainly due to the difficulty in securing healthy broodstock.



The typical growth performance of yellowtail in four different sea areas in Japan is shown in Figure 3. Depending on water temperature, *Mojako* can usually be stocked from April through to July. In sub-tropical regions, such as Okinawa and Kagoshima, the average water temperature ranges from 20–24 °C. This optimal temperature range for farming yellowtail is stable for >75 percent of the year and it is possible to obtain >6 kilogram yellowtail within two years. In the Kyushu area, which includes Kumamoto and Nagasaki, the average annual water temperature ranges from 17–19 °C. This temperature is optimal for yellowtail culture for about 50 percent of the year and, due to the shorter culture



period when the temperature is optimal, over 70 percent of the yellowtail reared in this region are three years old at harvest. In the Honshu area, which includes Shizuoka and Yamaguchi, yellowtail can be farmed but the temperatures are not as favourable compared to the regions further south. The average annual water temperature is around 18–19 °C, and more than three years are required to produce 6 kilogram fish. A specific feature of this region is its short autumn, which provides the fish with insufficient time to prepare for winter. If the fish are pushed to grow rapidly during autumn, high mortalities may occur in winter and early spring, therefore, fish weighing from 3.5 to 4.5 kilograms are produced for the sashimi market.

In the Seto Inland Sea, the average annual water temperature is lower than 17 °C, with less than 50 percent of the year being conducive to yellowtail growth. The temperature falls below 10 °C during the last two months of winter, at which time yellowtail may experience mass mortalities. To avoid the mortality problem, the fish are transferred to warmer areas such as Kochi and Miyazaki for over-wintering. In spring, when the water temperature rises again the fish may be returned to the Seto Inland Sea and reared to the size appropriate for use in sashimi. Another widely used approach is to stock large juveniles from other districts in the spring. It is then possible to produce fish suitable for sashimi within a growing season.

Farming techniques

In 2004, yellowtail farming comprised 13 570 net cages and only 44 net enclosures. Most cage farms use fresh fish (524 670 tonnes) or artificial pellets (357 311 tonnes) as feed. An optimum density and proper feeding rate are essentials for an economic production of yellowtails. The optimum stocking density and feeding rate for maximum growth and feed efficiency, relative to season and fish size, can be ascertained from rearing records collected at a particular site for at least a 3-year period.

The health status of the farmed fish is regularly checked by observing swimming behaviour and using underwater visual equipment to observe feeding. Observations on the swimming speed of individual fish while feeding, the swimming activity of the fish shoal as a whole, and the colour of the fish are all important parameters to determine the health status of the cultured fish.

Culture mortality

Mortality in cultured yellowtail can be caused by four main factors: 1) physical damage arising from inappropriate handling and transportation, and contact with the cage netting during storms and strong tides; 2) turbid water and high levels of pollutants; 3) feeding of deteriorated fresh fish and nutritionally inadequate feeds; and 4) diseases. The survival rates and mortality causes in four growth stages of juvenile yellowtail are shown in Table 2.

TABLE 2
Survival rates and mortality causes in four growth stages of juvenile yellowtail from capture and the start of the farming operation

Growth stage	Weight (g)	Survival (%)	Mortality causes
<i>Mojako</i> (first introduction and domestication)	0.2–50	90–95	Stress Starvation
<i>Hamachi</i>	50–2 000	95–98	Diseases Rough handling Poor water quality
<i>Hamachi</i> (over-wintering)		90–95	Low temperatures Diseases
<i>Hamachi</i> and <i>Buri</i>	1 000–7 000	95–98	Diseases Transportation accidents
Overall survival			70–80 %

The damage to cultured fish from water pollution is increasing, as there are no sound measures in place to prevent environmental pollution around coastal/nearshore mariculture sites. To rectify this, investigations into restoring water quality by removing contaminants from urban and agricultural drainage and from aquaculture are underway. One promising technology for maintaining a clean environment that should be considered is the development and introduction of an auto-feeding system. A further solution could be the culture of yellowtail in offshore or in land-based closed systems. However although these approaches have produced high quality flesh and low pollution, they are not economically viable.

Disease is usually not a problem during the initial phases of rearing a particular aquaculture species, however, as the number of yellowtail farms increase around Japan, disease outbreaks have become frequent. High density stocking and overfeeding make the fish more susceptible to diseases, which then can spread rapidly among the fish. The importation of wild fry, fingerlings and juvenile fish, especially from tropical waters, is also a source of disease. Environmental deterioration and nutritionally deficient feeds may aggravate the situation.

Initially, diseases were easily controlled by reducing or stopping feed, or by administering antibiotics. However more comprehensive approaches are now required particularly as a crucial step for disease management is to remove the cause. In order to identify the causes and prevent disease outbreaks, detailed records should be kept, especially when mass mortality occurs. Removal of sick and dead fish from the net pens is a first step in the prevention of further spread of disease. Furthermore, the amount of feed consumed in net pens where disease has occurred should be documented as sick fish will not feed as well as healthy fish. It is usually necessary to reduce feeding to 60–70 percent of the normal rate.

The most common disease in yellowtail is caused by the bacteria, *Enterococcus seriolicida*, which is diagnosed by simply identifying gram-positive bacteria using STAN agar. Other significant problems with producing yellowtail and related species in warm waters include muscle parasites and ciguatoxin (a toxin in fish tissues that derives from dinoflagellates, and which causes poisoning in human). In the waters south of Kagoshima, aquaculture of these species is not feasible because of parasitism with the spore-forming myxosporean parasite *Kudoa*, which is found in the muscles and the internal organs. Among viral diseases, iridovirus is noteworthy. This virus was introduced with wild juveniles imported from tropical areas, and resulted in mortalities of juvenile yellowtail and amberjack in Japan.

DESCRIPTION OF THE FISHING ACTIVITY

Yellowtail spawning areas and seasons have been described by the Japan National Sea Fisheries Research Institute of the Fisheries Research Agency (Figure 4). In the southern parts of the East China Sea, the fish spawn from early February until April. Following spawning the young *Mojako* drift to the Pacific Ocean in association with floating seaweed. Off the west coast of Kyusyu, spawning occurs mainly from March to June and most of the *Mojako* drift through the Tsushima warm current to the Sea of Japan. Spawning areas and seasons move north to the 20 to 22 °C water temperature off Sizuoka from May to June, and to Toyama from July to August.

Fry of yellowtail and related species seek protection in seaweeds that break off the bottom of the sea, and feed on micro-organisms and small fishes while drifting north with the current. Small *Mojako* (4–5 cm long) usually stay under or inside the floating seaweed, while larger fish swim 0.5–2 m below the surface. *Mojako* feed actively at sunrise and sunset when swarms of zooplankton can be detected; during the day they feed on small fish (Sakakura and Tsukamoto, 1996; Anraku and Azeta, 1967). After reaching 10–14 cm in length, the *Mojako* leave the floating seaweed and swim towards the shore, where they are targeted by the set nets (Ikehara, 1984).

Wild *Mojako* juveniles for aquaculture are harvested from the floating seaweeds, by experienced crew using specifically designed fishing vessels (Figure 5). In contrast, wild yellowtail for human consumption are caught using set nets, tow nets and round haul nets from the shore.

Statistics and trends in the amount and sizes of juveniles caught

The number and size of *Mojako* captured by the prefectural fisheries organizations have changed in recent years, largely due to changes in the amount of drifting seaweed in the South Seas (Table 3). Furthermore, the size of captured *Mojako* differs by area and month, influenced by water temperature and nutrients in the sea.

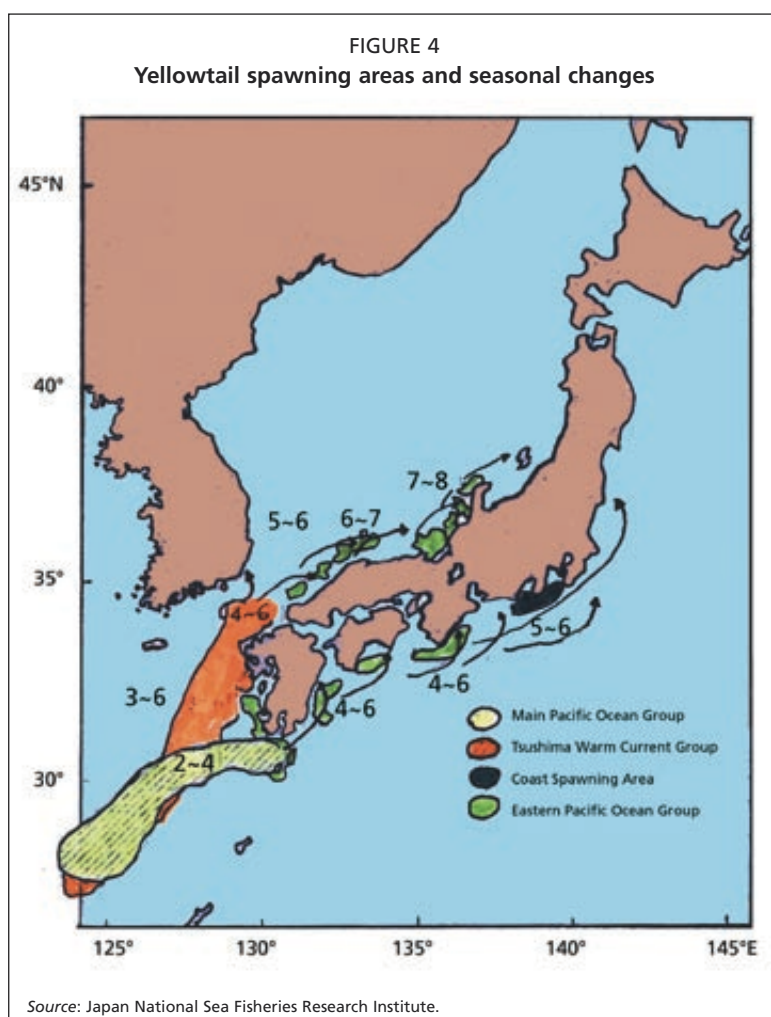
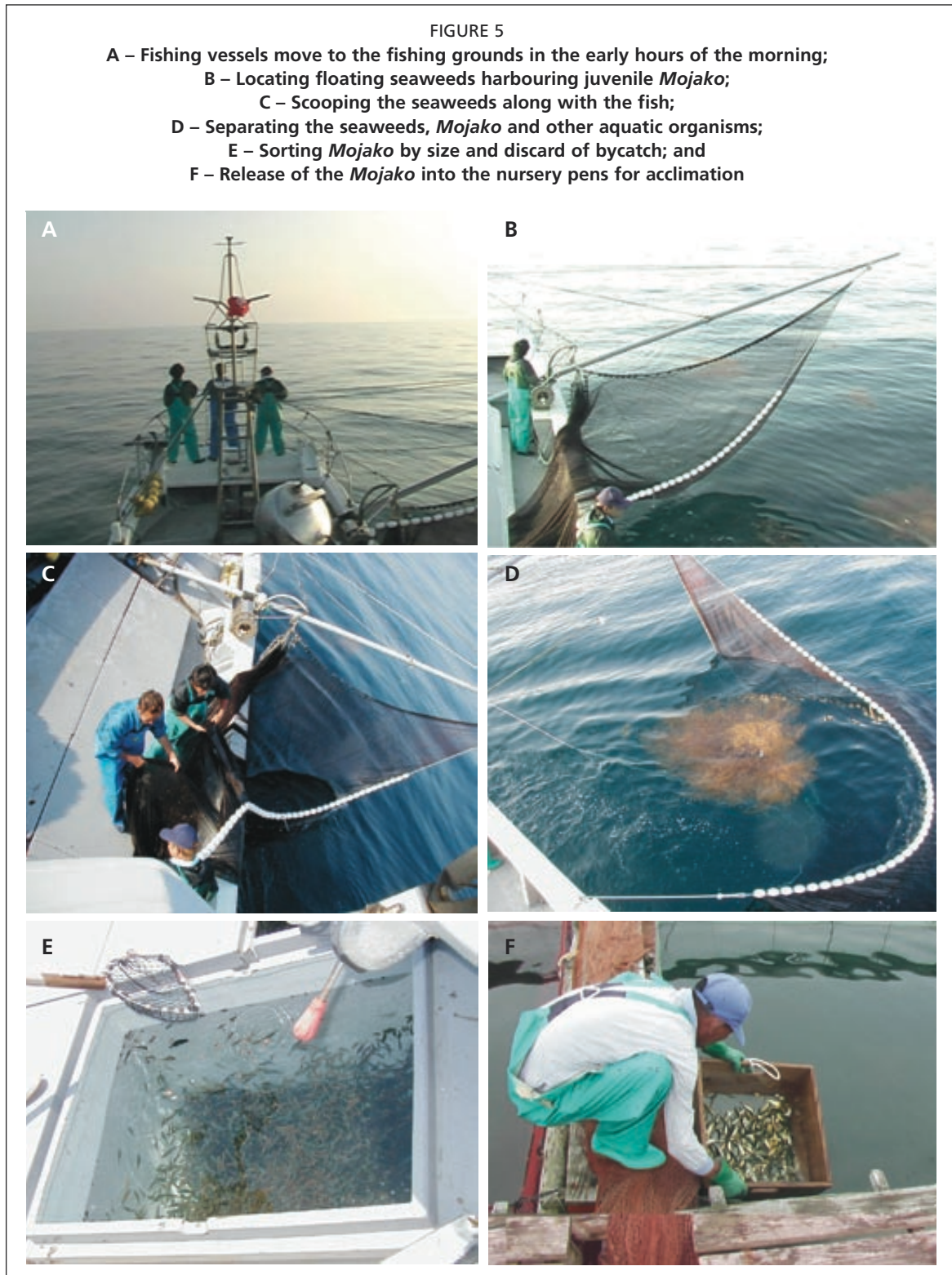


TABLE 3
Number of enterprises and number of juvenile yellowtail stocked in pens in 20 prefectures on 1 September 1997 (Unit: 1 000 fishes). Data not available for Saga Prefecture

Prefecture	Enterprise	1 st year	2 nd year	3 rd year	Total
Chiba	5	35	43	0	78
Ehime	281	6 480	5 170	8	11 658
Fukui	1	0	7	0	7
Fukuoka	6	5	0	0	5
Hiroshima	10	0	270	150	420
Hyogo	12	129	95	0	224
Ishikawa	0	0	0	0	0
Kagawa	0	0	0	0	0
Kagoshima	285	4 405	1 872	30	6 307
Kouchi	78	1 984	417	0	2 401
Kumamoto	60	850	650	0	1 500
Kyouto	4	0	25	0	25
Mie	58	785	121	0	906
Miyazaki	26	558	359	112	1 029
Nagasaki	146	2 908	2 486	441	5 835
Ohoita	71	1 519	1 373	150	3 042
Shimane	4	63	222	4	289
Sizuoka	32	275	222	13	510
Tokushima	17	714	146	0	860
Yamaguchi	21	107	93	4	204
Total 1997	1 123	21 045	13 679	914	35 638
Total 1996	1 369	24 996	27 389	918	53 303
'97 as % of '96	82.0	84.2	49.9	99.6	66.0



Seasonality of fishing activities

From early March, the early juveniles (*Mojako*) are collected from drifting seaweed and then raised until they reach 2 000 g, which is achieved by the end of the year. The harvest season and size are regulated by the fisheries station in each prefecture. Usually the *Mojako* season opens in May at Kagoshima Prefecture, and in June at Mie Prefecture.

Participants in the fishery and their roles

Mojako fishing is dangerous work in rough seas, and workers need experience, special knowledge and intuition. After harvest, the juvenile fish are put into small net cages (5 x 5 x 5 m), and older workers feed them with minced raw feed fish or granulated feed more than 5 times per day. The former feed type is problematic, because it quickly pollutes the water, the *Mojako* lose their appetite and may develop gill problems. The granulated feed is preferred, and is given as soon as possible, even while the juvenile *Mojako* are in the holding tanks on the fishing boats. Granulated feed for marine juvenile fish results in a high survival and growth rate, and *Mojako* as small as 0.2 g easily domesticate and grow well.

Larger yellowtail *Mojako* are fed extruded pellets weighing 5 g or more, twice daily. As the fish grow, they are graded and transferred into 7 x 7 x 7 to 10 x 10 x 10 metre net cages. When the fish become 200 g or more (called *Hamachi*), they are fed moist pellets, which are prepared by the younger workers on the boats and distributed via mechanical feeders.

Seed handling procedures at sea

If the fishing areas for *Mojako* are very far from port, there is a long period when the fish are held on board, during which time the juveniles may prey on each other whilst in the holding tanks. To reduce cannibalism, they are fed minced fish which often causes the water to deteriorate rapidly due to food wastes and faeces. Newly developed granulated feeds have been fed successfully to the juveniles during transport to the net cages. These feeds have a high palatability, do not pollute the holding water and are easily taken by fish as small as 0.2 g. Wild *Mojako* weaned on granulated feed tend to perform well during subsequent culturing.

AQUACULTURE DEPENDENCY ON WILD SEED

In the 1980s, the wild catch of *Mojako* started to decline. In order to protect this natural resource the Japan Fisheries Agency required the Marine Aquaculture Association of Japan to regulate both the catch season and numbers (Figure 2) and since 2003 the Prefectural Fisheries Cooperatives are allowed to regulate this fishery and allocate quotas to each prefecture (Inagaki, 1990). However, when the number of *Mojako* caught has been insufficient, yellowtail fingerlings have been imported mainly from the Republic of Korea. Amberjack juveniles have been imported from China and Viet Nam, including some 20 million imported in 2000 which were cultured from wild amberjack seed. These are acclimated and reared to 50 to 300 g. Several viral and parasitic diseases have entered Japan with the imported juveniles. In 2005, the nematode worm *Anisakis*, which was introduced with juvenile amberjack from China. Because *Anisakis* larvae in fish can be transmitted to humans, the Japanese Ministry of Health, Labour and Welfare prohibited sales of the infected farmed fish for raw meat consumption. Concerns over the health of imported juveniles have persuaded some fishing cooperatives to send workers to China to conduct quality control on the health of the amberjack juveniles. Furthermore, all imported amberjack juveniles are also checked by custom officials as they are often fed with high levels of antibiotics prior to shipping.

A further and important seed source is aquaculture itself. The Marine Aquaculture Association of Japan and several prefectural experimental stations have established techniques for the artificial production of about 60 marine fish species. Significant quantities of yellowtail, amberjack, gold-striped amberjack and striped jack juveniles have been produced by aquaculturists (Kawabe *et al.*, 1996; Arakawa *et al.*, 1987; Tachihara, Ebisu, and Tukasima, 1993; Kawanabe *et al.*, 1997). Viable eggs are obtained from both wild spawners and cultured broodstock fed high quality formulated feeds, with maturation being stimulated by hormone injections in many instances (Mushiake *et al.*, 1993; Nagasaki Prefectural Fisheries Experimental Station, 1998). Healthy fry

are fed on mass-produced food organisms such as rotifers and brine shrimp nauplii fortified with n-3 highly unsaturated fatty acids (HUFA) as well as formulated feeds (Verakunpiriya *et al.*, 1997a; Verakunpiriya *et al.*, 1997b; Fukuhara, Nakagawa and Fukunaga, 1986). Farm-raised juveniles have been released into the wild and used as seed for aquaculture.

Production benefits from aquaculture

For more than 30 years, the annual yellowtail capture fisheries harvest in Japan has been around 50 000 tonnes, while 160 000 tonnes are produced from aquaculture. The fishery is carried out using different fishing techniques and takes place in numerous fishing grounds along the extended coast of Japan. At present, the fisheries stations in the prefectures, along with the Japan Fisheries Agency monitor the wild resources and make recommendations to prevent excessive harvest of *Mojako*, juveniles and adults.

If wild *Mojako* harvesting was limited to what is needed for aquaculture, wild yellowtail fisheries could increase to more than 100 000 tonnes, however the wild yellowtail might then consume more than 1 000 000 tonnes of prey fish, which could otherwise be harvested for human food. It is suggested that wild *Mojako* and small jacks should be fully utilized as a resource for aquaculture, as they have very high natural mortality rate in the early life stages. Farm feeds could include artificial granulated feed, moist pellets, and extruded pellets made from trash fish and vegetable matter as well as human food left overs.

FISH FEED

Reliance on wild-caught food

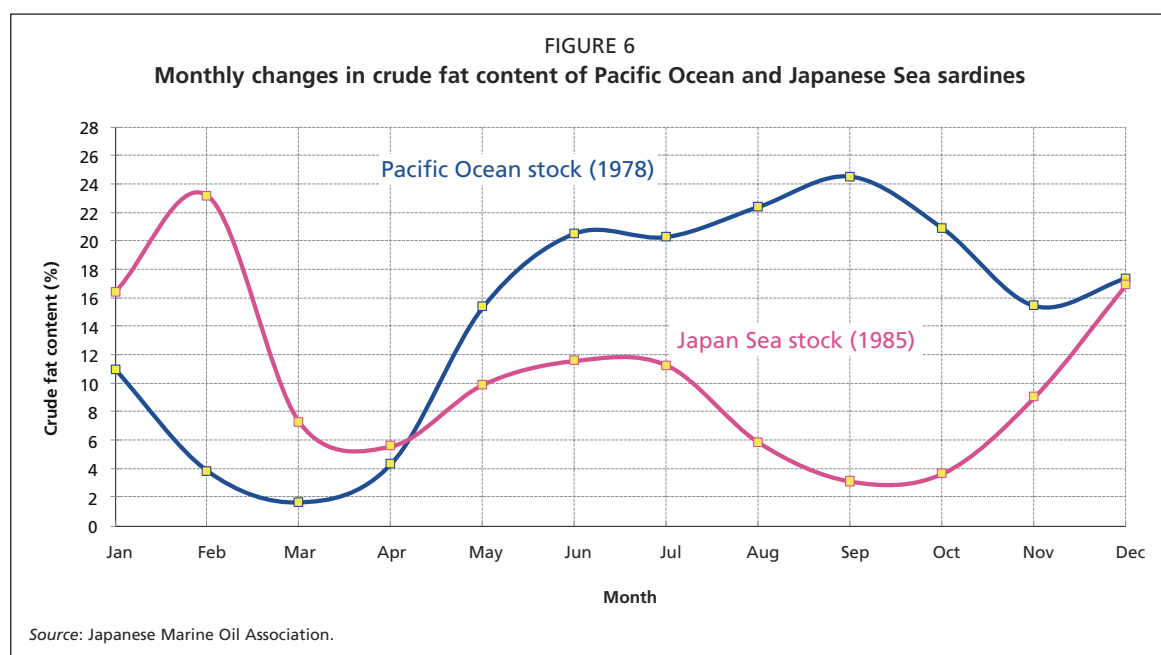
In the early years of yellowtail culture in Japan, there was a high dependence on locally available trash fish for feed. However, as yellowtail culture techniques were disseminated, the demand for trash fish exceeded production, and different resources had to be used that included commercially available small pelagic fish such as sardines which were abundant and cheap. The government supported the installation of large-scale freezing plants along the coast and frozen sardines further supported the development of yellowtail aquaculture. Minced frozen sardines were widely used; however feeding efficiency was poor and water quality deteriorated rapidly due to accumulation of uneaten fish and faeces. However, after determining that feeding frozen fish was safe, and was better than feeding thawed fish, frozen sardines were fed cut into pieces or whole (Miyazaki, 1986). Two of the major advantages with the use of frozen fish were reduced deterioration of the feed and reduced environmental pollution.

However, the use of sardines alone as the sole feed for yellowtail led to nutritional disorders, because of unsuitable calorie/protein levels. Furthermore, the crude fat content of sardines changed markedly with harvest areas and seasons (Table 4), and between the stocks in the Pacific Ocean and Japanese Sea (Figure 6). While a good system for distributing sardines to fish farmers was developed, there was no control over their fat content. There is a strong, negative correlation between the water and fat content of sardines landed at Kyushu, Sanin and Kushiro.

TABLE 4
Difference in crude fat content of sardines according to harvest area

Harvest area	Fat content – range (%)	Fat content – mean (%)
East Hokkaido	19.9–39.9	26.8
Boso: Joban	8.8–22.5	14.4
Sanin	1.4–22.3	13.0
Kyushu	4.0–13.6	8.6

Sources: Japan Marine Oil Association.



More recently, the catch of wild fish as feed has markedly declined. For example, the harvest of sardines between 1980 and 1990 was more than four million tonnes. These were used to feed farmed fish such as yellowtail, red seabream, and silver salmon as well as being transformed into fishmeal. However, after 2003 only 50 000 tonnes of sardines were locally fished. Fresh fish feed for yellowtail farming decreased over the years from 1.7 million tonnes to 0.88 million tonnes (including mainly sardines, horse mackerel, mackerel and sand lance). At the same time the total production of cultured yellowtail has been maintained at around 150 000 tonnes due to the development of artificial feeds such as moist and extruded pellets (Table 5).

TABLE 5
Temporal changes in quantities of fish and artificial feeds used in yellowtail aquaculture (tonnes), 1994–2006

Year	Feed fish (tonnes)	Artificial feeds			Dry pellet as % of total
		Powder	Dry pellets	Total	
1994	1 159 724	71 747	28 684	100 425	28.6
1995	1 748 843	86 449	54 282	140 731	38.6
1996	1 105 152	59 273	48 977	108 250	45.2
1997	1 197 292	60 889	60 063	120 952	49.7
1998	1 258 991	61 527	65 207	126 734	51.5
1999	1 060 763	50 891	67 894	118 785	57.2
2000	983 836	56 211	97 260	153 471	63.4
2001	929 691	59 483	138 908	198 391	70.0
2002	1 048 747	54 223	138 378	192 601	71.8
2003	965 701	49 521	153 241	202 762	75.6
2004	881 981	49 173	147 518	196 690	75.0
2005	NA	44 327	148 400	192 727	77.0
2006	NA	47 580	157 505	205 085	76.8

Source: Japanese Fish Feed Association.

TABLE 6
Feed intake efficiency (Feed Conversion Rates) and feed cost (¥/kg)

Type of feed	Yellowtail life stage	Feed intake efficiency (%)	Feed conversion rate (Dry weight)	Feed price (Yen/kg)	Feed cost ¹ (Yen/kg)
Minced raw fish	Mojako	25	17.5 (6.1)	100	1 750
Minced raw fish	Hamachi	25	12.5 (4.4)	80	1 000
Granulated feed	Mojako	55	4.5	400	1 800
MRF + binder	Hamachi	45	8.5 (3.2)	60	510
Round raw fish	Hamachi	50	10 (3.5)	45	450
Round raw fish	Buri	50	7.5 (2.6)	45	338
Moist Pellet 0	Hamachi & Buri	50	11 (3.9)	55	605
Moist Pellet 30		60	6.5 (4.0)	92.5	600
Moist Pellet 50		70	5.0 (3.3)	117	585
Moist Pellet 100		80	4	140	560
High Fat Dry Pellet	Mojako	70	3.7	150	555
High Fat Dry Pellet	Hamachi	75	5	140	700
Extrude Pellet	Mojako	85	0.9	325	300
Extrude Pellet	Hamachi	75	1.4	250	350
Extrude Pellet	Buri	65	2.4	175	400

¹ Cost of feed to produce a kg of fish.

Extruded pellets containing more than 20 percent fat are efficiently utilized by yellowtail, and farmers have achieved feed conversion ratios of 1.2 during the production of 1-year old fish. Using the same type of feed, satisfactory growth has also been achieved during the second year, providing that water temperatures are optimal. For yellowtail larger than 3 kilograms, raw fish is preferred to extruded pellets, and it is difficult to attain daily feeding rates of 2 percent of the body weight on extruded pellets, especially during the winter. Development of an extruded pellet, containing >25 percent fat and weighing more than 30 g, will be required for the economical production of yellowtail larger than 3 kilograms, particularly during the winter months.

Artificial feed availability and problems

Artificial feeds support improved growth and survival rates when compared to fresh fish diets. When raw fish were used as the primary feed material for yellowtail, it was difficult to predict fish growth precisely because the nutritional composition of the feed varied significantly. As information on the protein and vitamin requirements of yellowtail was acquired (Takeuchi *et al.*, 1992), the production of various types of moist pellets and formulated feeds became possible. Currently the production cost for yellowtail moist pellets or formulated feed is less than that of raw fish, prompting numerous feed manufacturers to produce such feeds.

Although the quantity of formulated feed used for yellowtail culture has increased almost linearly over the last decade (see Table 5), more research is needed to develop dry pelleted feed, appropriate feeding techniques and identification of inexpensive feed materials (Nakada, 1997a; Shimeno, Masaya and Ukawa, 1997; Nakayama, 1997). The development of high quality formulated fish feeds is now being undertaken by the Fisheries Agency of Japan, the Fish Feed Association of Japan, university researchers and fisheries experimental stations (Matsumoto, 1997). The development of artificial feeds such as Umisachi and Otohime has contributed to the increased production and high survival of *Mojako*. By using such feeds it is now possible to raise healthy *Mojako* starting from initial sizes of >2 g; when raw minced fish was used as feed, high survival rates were not possible.

The Fish Feed Association of Japan supported the development of economical moist pellets, extruded pellets and granulated feeds for yellowtails that successfully lowered production costs and improved product quality. In addition, pharmaceutical companies developed vitamin mixtures and functional ingredients for the prevention and treatment of disease and improvements of fish quality.

Another advance in artificial feed came in 1979 when the Japanese Fisheries Agency started to develop a moist pellet diet for yellowtail culture in order to prevent pollution. However, during the 1980s the abundant and extremely cheap domestic spot-lined sardines continued to be used as the principal feed for yellowtail. It was not until the early 1990s that fish farmers finally became aware of the severe damage to the environment around their aquaculture grounds caused by feeding fish, and this prompted acceptance of the artificial feeds

Modification to the feed can include the addition of binding agents, which, when added to minced raw fish, improve the feed efficiency by almost twofold. The daily feeding rate can then be reduced by 20 to 30 percent, resulting in a better feed conversion rate and reduced water pollution. The use of the right feed in the appropriate amount is a very important factor for efficient and sustainable production, which can in turn improve cultured fish quality (Table 6).

Various substitutes for fishmeal have been successfully used to halve the amount of fishmeal and fish oil in yellowtail feeds without adverse effects (Watanabe, 1996; Shimeno, 1997; Shimeno, Takii and Ono, 1993). If defatted and dried fishmeal is used in aquaculture, fish feeds have insufficient lipid content in the absence of added fat (Nakada, 1992).

During the 1980s it was common practice to provide supplemental oil in feed for freshwater fishes, however, these oils could not be used for marine species due to their difference in fatty acid requirements. Feed oils suitable for marine species were developed and tested in commercial production trials with yellowtail, and produced fish similar in lipid composition to wild fish. However, the quality of oil containing high levels of highly unsaturated fatty acid (HUFA) varies, so the Society of Aquaculture Feed Oil Research has set standards for feed oils recommended for aquaculture feeds. Since world production of fishmeal and fish oil has fluctuated dramatically, further improvements in fish feeds, including use of alternative protein sources, has been undertaken. In the future, soybean meal, poultry meal and a certain amount of fish oil, along with soybean oil and/or coconut oil, will likely be used in place of the current fishmeal which is currently the major protein source in formulated feeds.

Sustainability of wild-caught feed

Under strict regulations from the Japan Fishery Ministry, the sardine resources are stable at low harvest levels. According to the 2004 statistics of the Japan Fishery Agency, feed fish production for yellowtails was 525 000 tonnes, and artificial feed production for yellowtails was 357 000 tonnes. As the sardine stocks are not increasing, sardines should not be harvested at levels greater than the previous year, and yellowtail culture will need to switch to artificial feeds.

ENVIRONMENTAL IMPACT OF JUVENILES FISHERIES

The annual *Mojako* stocks are estimated to be greater than 100 million specimens and current regulations limit harvest to 25 million. In order to enhance this natural resource and reduce impacts on the wild stocks, a number of actions have been taken over the years which included the establishment of suitable algal grounds to encourage yellowtail reproduction, release of artificial drifting seaweeds and artificial propagation. During the fishing of *Mojako*, non-targeted species bycatch is reported to the designated Prefectural Fisheries Station. Some valuable bycatch species are handled with care and may be retained, while other species are released back to the sea along with the drifting seaweed.

Following capture of the *Mojako*, the fishing vessels return to port within two days to minimize cannibalism, and if transportation time exceeds 3 days artificial granulated feed is provided to the fish in holding tanks. Since the early days, the traditional *Mojako* fishing technique has improved considerably, ensuring that the young fish

remain in good health. Proper handling and feeding during these early stages will ensure almost complete survival of the wild fingerlings during subsequent farming (<2 percent mortality).

SOCIAL AND ECONOMIC IMPACT OF FARMING

Two million people are estimated to be engaged in mariculture in Japan, with women and older workers involved in all stages of yellowtail culture and trade except for harvest of the wild fish. Most yellowtail products are handled by the fishermen's cooperative association (FCA) which also provide working capital (as loans) to purchase seed and feed. Traditionally, the FCA used to sell the products to the fish markets in neighbouring towns and cities. However, more recently, supermarket chains purchase the product at lower prices in order to guarantee their yearly contracts. Hence producer's prices and farmer's profits have fallen.

In an effort to create higher returns, there has been an increase in intensive net pen culture, which has in turn caused water pollution, increased the occurrence of red tides, but also decreased the number of feeding days. Many family-owned aquaculture businesses have gone bankrupt as they have been unable to keep up with the production costs. Such businesses have transferred their aquaculture rights to others and have often become employees of such new operations. The number of existing mariculture farms has declined dramatically.

Although consumers in Japan can purchase cheaper and higher quality fish from the new chain of discount shops, the purchasing power of the Japanese public has decreased because of the extraordinary demand for quality and low prices in international competition.

Trade of farmed fish

The consumer is gradually accepting cultured fish as being of higher quality than wild fish, although high level restaurants still prefer wild rather than cultured fish. The strongest competitor for cultured yellowtail is not pork or beef, but wild small *Buri* (50–60 cm in body length) caught using set nets. If a large quantity of young *Buri* is landed at one time, their market price may drop as low as ¥200–300/kg (US\$1.9–2.9/kg), which is significantly cheaper than the lowest price for cultured yellowtail of ¥800/kg (US\$7.7/kg).

The market for cultured yellowtail can be divided into that for (i) high class Japanese restaurants that deal mainly in live fish, (ii) wholesale stores and supermarkets dealing with fresh and frozen fish, and (iii) direct delivery of processed fillets to individual restaurants and homes (Satoho and Homma, 1990).

Although yellowtail was once sold strictly by weight, consumers have now become more selective about product quality, and farmers have started to produce higher quality fish. Currently, branded farmed yellowtail fetch a higher price than other yellowtail and other cultured fish. Maintaining a stable quality product by discarding second grade fish, and paying special attention to maintaining freshness has become highly valued by the intermediate dealers. At supermarkets and retail fish stores, sales have expanded through the marketing of special brands of cultured fishes produced by such organizations as the Kagawa and Kagoshima Federation of Fisheries Cooperatives.

In order to maintain a high product quality, the fish should be fasted before harvesting, as it allows consumed food to be digested. Furthermore, to retain product freshness, the fish should be killed immediately after being taken from the water by severing the *medulla oblongata*, and bled by cutting the caudal artery. If it is impossible to treat the fish individually, they should be held in a tank with a large amount of chipped ice. If the moribund state is prolonged, or the fish are shipped without enough chilling, early *rigor mortis* reduces product quality. The quality of fish deteriorates very

rapidly and it is vital to get the fish product to consumers quickly after harvest. With cold storage, fish can be served as sashimi for approximately three days, depending on rearing conditions and treatment after harvest. Rapid killing, bleeding, filleting, and proper packaging and refrigeration, can result in excellent quality yellowtail. Amberjack and gold-striped amberjack are more popular than yellowtail for sashimi as they can be kept for >3 three days under refrigeration without losing flavour, colour and firmness. Currently, demand for amberjack exceeds the supply.

Economic benefits and losses from aquaculture

Among the different parties involved in yellowtail aquaculture, the distributor usually gains the greatest economic benefit. The fishery cooperatives and fishing companies cooperate, manage the seed supply and marketing, and sometimes dominate management. Farmers receive relatively little economic benefit, and have thus become relegated to being only fish producers. Many aquaculturists sell their products through a relatively new system of direct sales, where private brokers buy fish directly from the producers and transport them to consumers using live-fish trucks. However, despite its popularity, many private brokers are experiencing difficulties because of serious “price competition”.

Seed production by artificial incubation for high priced fish can be lucrative. In comparison with adult fish culture, the seed fish business can easily be carried out, requiring only small ponds and limited technical knowledge. However, income from hatchery operations faces strong competition from seed material from the wild.

Fish farmers are currently also facing economic difficulties due to the stagnant national economy which has increased competition among the producers and brought a drastic decrease in the yellowtail market prices. There has been a 75 percent decrease in the number of yellowtail farmers in the last 30 years from the 4 162 enterprises in 1978 to 1 049 enterprises in 2004.

There are no full-time *Mojako* fishermen as this activity is rather a part-time job undertaken along with other fishing activities. Yellowtail farmers have concentrated in maximizing production and profits rather than determining proper farming densities and feeding regimes. Hence, management techniques have not developed. In 1999, legislation was enacted setting limits on the number of individual cultured fish per unit area, the amount of feed used and the number of cages per given area; this legislation is strictly enforced.

CONCLUSIONS

An urgent need in Japanese yellowtail aquaculture is the production of better quality juveniles, with better growth rates and less vulnerability to disease. This should be accomplished through selective breeding, which requires collection of different strains in order to select the required broodstock.

A further additional development may be culturing marine species, such as yellowtail, on land. If the culture of yellowtail and related species becomes possible on land without polluting coastal areas, it will be a welcome approach for producing high quality fish (Kikuchi, 1998). Previously land-based culture was not considered because of the high initial cost for facilities; however it may now be a feasible approach. The fish can be raised in controlled quality water, resulting in fewer diseases and reduced exposure to pollutants. This approach is attractive to consumers, who increasingly prefer cultured fish which they know have not received medication. A moist pellet for yellowtail was developed ten years ago, as well as formulated feed. Furthermore, artificial seawater systems that perform better than natural seawater for larval production have been developed and techniques for closed systems and automatic feeding systems are improving regularly (Nakada, 1997b). However, there remains the problem of finding suitable heat sources to control water temperature.

At present, there are no proper countermeasures for the declining productivity of the fish in growout areas, or for controlling disease in intensively cultured fish. For economical and sustainable fish culture it is necessary to maintain an optimum stocking density based on carrying capacity. Hirata and his colleagues (Hirata, Kadowaki and Ishida, 1994) proposed developing a distribution graph of dissolved oxygen concentrations in culture areas to aid proper water management. This can now be supported by the recent availability of real time information on the dissolved oxygen and water temperature of particular areas from the fisheries experimental station and fishery cooperatives.

In order to alleviate the environmental problems associated with marine fish farming, various measures are needed such as dredging accumulated sediment from the sea bottom, using chemicals to stimulate decomposition of organic materials, prohibiting the use of minced raw fish, and prohibiting the culture of large yellowtail in favour of culturing smaller, less polluting fish. Additional measures include increasing the propagation of lugworms, which consume organic material in the mud, and cultivating algae, which absorb dissolved nutrients excreted by fish. The comprehensive utilization of natural productivity may be the correct direction of aquaculture in the future (Tsutsumi and Montani, 1993).

It is time to consider a comprehensive culture approach that utilizes the natural purification ability of the environment. Such an approach may involve polyculture not only of several species of fishes, but also of crustaceans and algae (Hamauzu and Yamanaka, 1997).

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Capture-based aquaculture of groupers

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SUMMARY

The economies of China and Southeast Asia have developed rapidly over the past two decades, leading to the emergence of a wealthy class with substantial disposable income. This has led to an increasing demand for fish in the region (Birkeland, 1997). The “live fish trade” of the Indo-Pacific has expanded rapidly in recent years, and now targets many species (Johannes and Riepen, 1995; Sluka, 1997, Sadovy and Vincent, 2002). Groupers are greatly valued for the quality of their flesh, and most species command high market prices. Groupers are the most intensively exploited group in the live fish trade, and the high prices paid by exporters to local fishermen mean that target species may be heavily over-fished (Morris, Roberts and Hawkins, 2000). In order to alleviate the pressure on wild grouper stocks, many nations have promoted aquaculture in the hopes of producing a more sustainable grouper yield. However, full-cycle culture of most grouper species is not yet possible, although several important advances have been made in recent years. For this reason, about two-thirds of all grouper culture involves the capture and grow-out of wild seed (Sadovy, 2000). This is known as capture-based aquaculture (CBA).

There are at least 16 species of groupers that are cultured in many Southeast Asian countries, including Indonesia, Malaysia, Philippines, Taiwan Province of China, Thailand, China Hong Kong Special Administrative Region (SAR), the southeast of the China and Viet Nam (Sadovy, 2000). Grouper culture is also undertaken in India, Sri Lanka, Saudi Arabia, Republic of Korea, Australia, the Caribbean and in the southeastern United States of America. Despite the huge popularity of live fish in China and Southeast Asia, only 15–20 percent of the amount consumed each year comes from aquaculture, as culture is principally constrained by limited and unreliable supplies of wild seed and the difficulties of spawning in captivity.

Grouper seed is collected using a variety of methods. Capture methods are generally artisanal and the fishermen employ a variety of artificial habitats. Some grouper seed collection methods are more damaging than others. Clearly destructive methods include those that result in high mortality, involve high levels of bycatch, and/or cause damage to the fish habitat. A further problem is that some methods result in monopolization of

the local fishery by a few individuals. Destructive methods include scissor nets and fyke nets, which are already banned in some areas. The mortality rates that follow capture and transport are not well documented; estimates for over the first 2 months after harvest are quite variable (30–70 percent), depending on the quality of fry, the level of transport stress, and the presence of disease and cannibalism (Pudadera, Hamid and Yusof, 2002).

Because full-cycle culture of most grouper species is not yet possible, approximately 66–80 percent of all grouper culture involves the capture and grow-out of wild seed and the volume of seed caught each year exceeds hundreds of millions of individuals (Sadovy, 2000). When seed catches are compared to the numbers of marketable fish produced, the results strongly suggest crude and wasteful culture practices. Sadovy (2000) estimated that about 60 million seed fish are needed to produce the regional total of 23 000 tonnes of table-size live fish from culture annually.

Trash fish is commonly used for feeding in grouper cage culture, but its increasing cost, shortage of supply, variable quality and poor feed conversion ratios indicate that this form of feed may not be the best from either a nutritional or an economic point of view. A dependable supply of cost-effective, non-marine, sources of alternative protein must be provided if grouper farming is to remain profitable. Millemena (2002) demonstrated that up to 80 percent of fishmeal protein can be replaced by processed meat meal and blood meal derived from terrestrial animals with no adverse effects on growth, survival, and food conversion ratio (FCR). From an economic standpoint, replacement of fishmeal with cheaper animal by-product meals in practical diets can alleviate the problem of low fishmeal availability and high costs.

Recent research suggests that the ecological footprint of capture-based grouper aquaculture is large (Mous *et al.*, 2006). Support for grouper CBA is often based on the assumption that the natural mortality of early juvenile grouper is very high, so that the fishery is not adding substantially to this natural mortality and therefore not affecting adult population size to any great extent. This assumption remains untested for most grouper species. However, recent research suggests that the period of very high mortality occurs during and immediately after settlement, and that juvenile grouper surviving more than a few days have a much higher chance of survival (Tupper, 2007). In addition to problems of bycatch, wasteful mortality, and overfishing, cage and net culture can create other environmental problems, most notably point-source pollution which can have adverse effects on coastal waters, and particularly on coral reefs.

As a contributor to rural livelihoods, particularly those of coastal fishers, grouper aquaculture can generate potentially large financial benefits. The high value of grouper on the export market ensures that farmers are able to generate a profit even when stocks suffer heavy mortalities. Despite high initial investment costs, studies have shown that with appropriate support, even the poorest can benefit from grouper culture, with implications for both household well-being and community development. However, based on the information reviewed in this report, capture-based aquaculture may not be the best means to ensure a steady and sustainable supply of grouper for either the live or “non-live” fish trades. This is due to a number of problems including low availability of seed, destructive and wasteful seed collection techniques, removal of large numbers of early life history stages with subsequent impacts on adult populations and conflicts with capture fisheries, and pollution and disease resulting from culture operations.

The obvious solution to some of the problems of CBA for grouper is to develop closed-cycle hatchery rearing for all the grouper species sought by the market. Important advances in full-cycle culture have been made for several species, particularly in Taiwan Province of China, and full-cycle culture appears financially feasible given a large enough capital investment. However, given the financial means of most grouper culturists, and the difficulty in rearing most grouper species, it remains unlikely that many of these species will be hatchery-reared in the near future. In the meantime, steps must be taken to improve the management of both CBA and capture fisheries for grouper.

INTRODUCTION

The economies of China and Southeast Asia have developed rapidly over the past two decades, leading to the emergence of a wealthy class with substantial disposable income. This has led to an increasing demand for fish in the region (Birkeland, 1997). The “live fish trade” of the Indo-Pacific has expanded rapidly in recent years, and now targets many species (Johannes and Riepen, 1995; Sluka, 1997; Sadovy and Vincent, 2002). Groupers are greatly valued for the quality of their flesh, and most species command high market prices. Groupers are the most intensively exploited group in the live fish trade, and the high prices paid by exporters to local fishermen mean that target species may be heavily over-fished (Morris, Roberts and Hawkins, 2000). Trade often follows a pattern of sequential over-exploitation; the most highly sought species are fished-out in country after country, before the less valuable species are targeted and fished intensively (Sluka, 1997; Johannes and Riepen, 1995). Wealthy customers pay very high prices for endangered species in Chinese and Southeast Asian markets. In 1997 the red grouper, *Epinephelus akaara*, fetched US\$42/kg in China Hong Kong SAR markets. In 2004, restaurants were charging US\$225 for only the lips of the humphead wrasse, *Cheilinus undulatus*. Thus, fishermen will go to great lengths in order to catch every fish, and this has already contributed to regional population crashes of species, including *Epinephelus akaara* and *Epinephelus striatus* (Morris, Roberts and Hawkins, 2000; Sadovy, 2001a).

The impact of intensive fishing is exacerbated by the K-selected life strategies of these genera, their tendency to form predictable spawning aggregations and their occurrence on relatively shallow, easily accessible coral reefs, which are severely over-exploited in many parts of the world. For many of these species, spawning aggregations represent the total reproductive output for a given year, and many species consistently return to the same aggregation area, year after year. Fisheries often target spawning aggregations, since they are consistent in time and space and large numbers of fish can easily be caught in a short time (Rhodes and Tupper, 2007). When fishing pressure removes a high proportion of the fish forming these aggregations, these may quickly decline, and within a few years may cease to form altogether (Johannes *et al.*, 1999; Sadovy and Eklund, 1999).

A large proportion of the world's groupers are caught in artisanal fisheries, and even low-level artisanal fisheries can adversely affect stocks of these highly vulnerable species. Recreational fishing may also have significant impact on stocks; for example, the recreational fishery of groupers accounts for up to 35 percent of Florida's (United States of America) total grouper catch (Morris, Roberts and Hawkins, 2000). The global catch of groupers showed a 68 percent increase from 100 724 tonnes in 1991 to 168 943 in 2000. In order to alleviate the pressure on wild grouper stocks, many nations have promoted aquaculture in the hopes of producing a more sustainable grouper yield. Because grouper are particularly difficult to culture in closed systems, full-cycle culture of most grouper species is not yet possible (although several important advances have been made in recent years). For this reason, about two-thirds of all grouper culture involves the capture and grow-out of wild seed (Sadovy, 2000). This is known as capture-based aquaculture (CBA).

There is a strong link between fishing activity and the capture-based seed used for farming, with declines in premium species from the overfishing of grouper adults. However, the reasons for this decline cannot be evaluated without careful, controlled studies, as falling catches may in fact be due to a combination of different causes: overfishing of the adults which produce the juveniles, habitat degradation and pollution, destructive fishing techniques, high export demand, etc. (Johannes, 1997; Sadovy, 2000). A more holistic management approach to establish the links between adults and juveniles is necessary.

SPECIES DESCRIPTIONS AND THEIR USE IN AQUACULTURE

Groupers (class Actinopterygii, order Perciformes, family Serranidae, sub-family *Epinephelinae*) comprise 14 genera and 449 species of the subfamily *Epinephelinae*, or roughly half of all species in the family Serranidae (groupers and sea basses) (Heemstra and Randall, 1993). There are 16 major grouper species that are cultured; the dominant species vary somewhat regionally. The most consistently abundant species that are captured for culture purposes and also reared in hatcheries are *Epinephelus coioides* and *E. malabaricus*. Other important species are *E. bleekeri*, *E. akaara*, *E. awoara* and *E. areolatus*. *E. amblycephalus*, *E. fuscoguttatus*, *E. lanceolatus*, *E. sexfasciatus*, *E. trimaculatus*, *E. quoyanus*, *E. bruneus*, *Cromileptes altivelis*, *Plectropomus leopardus* and *P. maculatus* are cultured in small amounts. In the southeastern United States of America and the Caribbean, *E. striatus*, *E. itajara*, *Mycteroperca microlepis* and *M. bonaci* seem to have good farming potential (Tucker, 1999). However, CBA for groupers in the western hemisphere has not been developed to any large extent, unlike in Southeast Asia.

Juveniles and adults of some grouper species live in coastal or lagoonal waters and estuaries, while others prefer the cleaner waters of offshore reefs. Their eggs are single, non-adhesive, and buoyant at normal salinities. The larvae of most species spend about 30–50 days as planktonic larvae (Colin, Koenig and Laroche, 1996). As they become juveniles, groupers settle in shallow waters where they seek shelter in seagrass beds, mangrove prop roots, coral rubble, branching coral or branching macroalgae. Some juvenile groupers are habitat generalists, settling in any available shelter, while other species have specific nursery habitats in which their growth and survival are enhanced (Tupper, 2007). After hatching, wild grouper larvae eat copepods and other small zooplankton. They switch to larger crustaceans, such as amphipods and mysid shrimp, as they grow. Wild juveniles and adults eat fish, crabs, shrimp, lobsters and molluscs (Tucker, 1999), although the genus *Plectropomus* tends to be predominantly piscivorous.

Groupers range in maximum size from only 12 cm (e.g. *Paranthias colonus*) to over 3 m (e.g. *Epinephelus lanceolatus*). Most groupers that have been studied are sexually mature within 2–6 years, but some of the larger species may take longer to mature, e.g. *Epinephelus fuscoguttatus*, which matures at about 9 years. Most serranids are protogynous hermaphrodites. As a rule, some change from female to male as they grow older; others may change only if there is a shortage of males. In nature, many species spawn in large aggregations (hundreds to thousands of fish) with a sex ratio nearing 1:1 (Rhodes and Sadovy, 2002). In some cases, several grouper species may share the same aggregation site (e.g. in Palau and Pohnpei; see Johannes *et al.*, 1999; Rhodes and Tupper, 2007).

Groupers are some of the top predators on coral reefs, and tend to be K-strategists demonstrating slow growth, late reproduction, large size and long life-spans which make them vulnerable to overexploitation. Also contributing to their vulnerability is the fact that they are sex-changers with a low proportion of males in the smaller cohorts, which means that heavy fishing pressure often removes most of the males (or removes fish before they can become male). Additionally, many groupers form spawning aggregations that are predictable in space and time, making them extremely easy to harvest. These aggregations can represent the entire annual reproductive output for some species. Groupers are sedentary in character and strongly territorial, making them easy targets for spear fisheries (Bullock *et al.*, 1992; Heemstra and Randall, 1993; Sadovy, 1996; Domeier and Colin, 1997; Sadovy and Eklund, 1999; Morris, Roberts and Hawkins, 2000). Tables 1–16 summarize the characteristics of grouper species most commonly encountered in CBA, while Figures 1–32 illustrate their appearance and geographical distribution.

Cromileptes altivelis (Valenciennes, 1828)

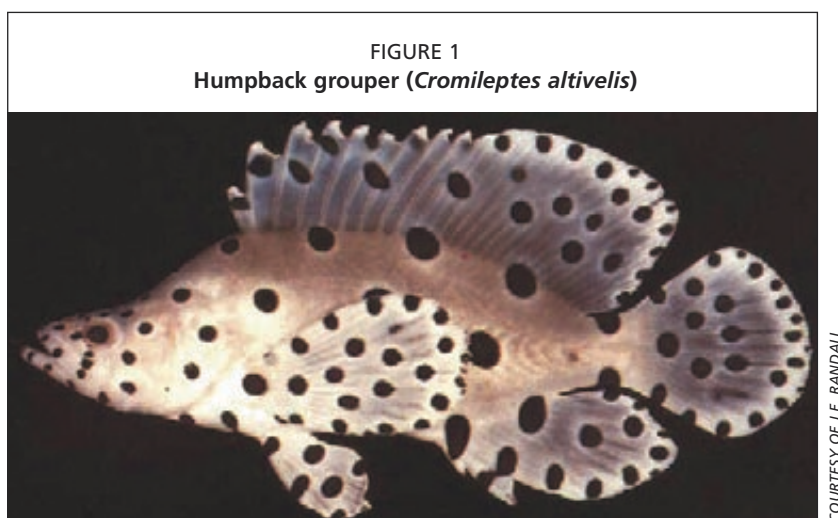
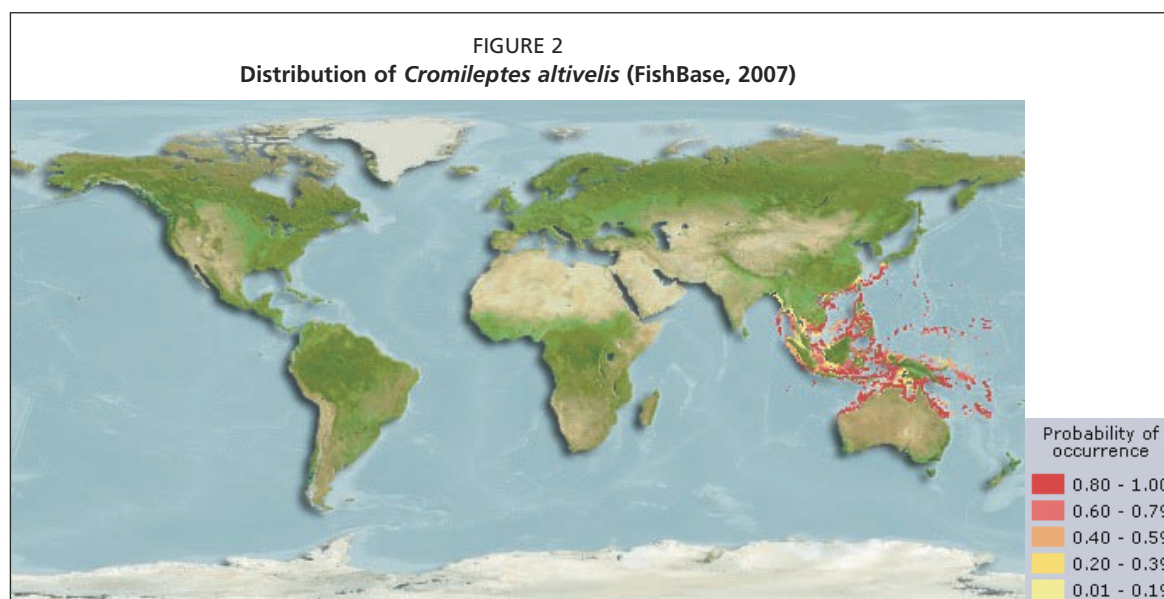


TABLE 1
Characteristics of the humpback grouper, *Cromileptes altivelis*

Common names:	Humpback grouper, panther grouper, mouse grouper, highfin grouper
Size and age:	Max size 70.0 cm TL
Environment:	Reef-associated; marine; depth range 2–40 m
Climate:	Tropical; 32°N - 23°S, 88°E - 168°E
Importance:	Juveniles are commonly caught for the aquarium trade while adults are utilized as a food fish. Very high value in China Hong Kong SAR live fish markets.
Resilience:	Low, minimum population doubling time 4.5–14 years.
Biology and ecology:	Generally inhabits lagoon and seaward reefs and are typically found in dead or silty areas. Also found around coral reefs and in tide pools. Growth is very slow. Feed on small fishes and crustaceans.

Source: Modified from FishBase (Froese and Pauly, 2007).

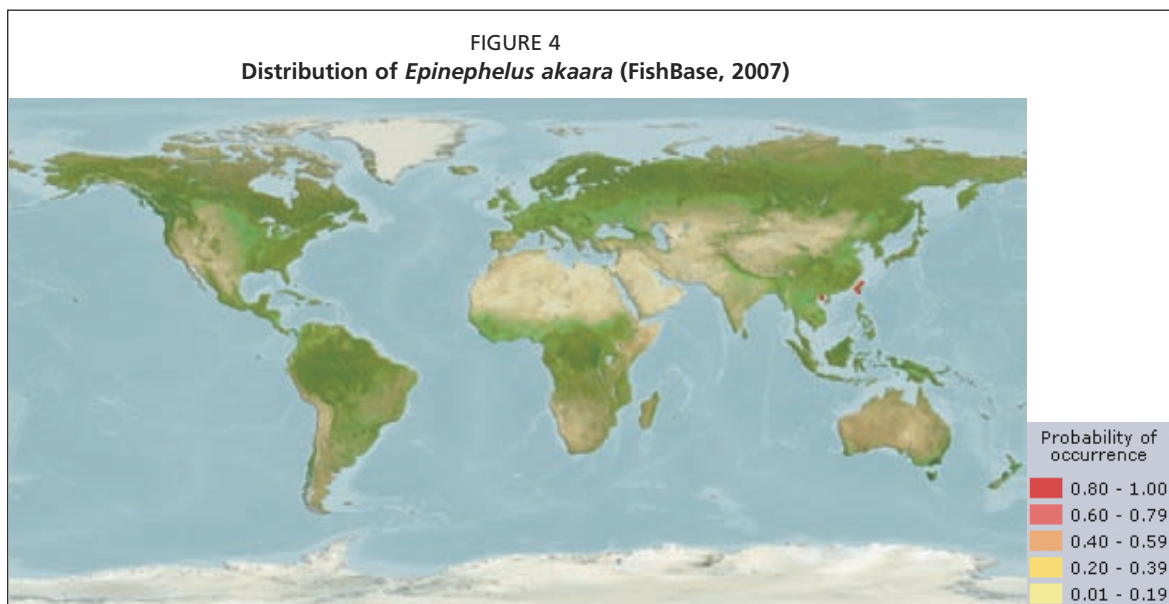


Epinephelus akaara (Temminck and Schlegel, 1842)

TABLE 2
Characteristics of the Hong Kong grouper, *Epinephelus akaara*

Common names:	Hong Kong grouper
Size and age:	53.0 cm TL; max. published weight: 2 470 g
Environment:	Reef-associated; marine
Climate:	Tropical; 39°N - 20°N, 109°E - 143°E
Importance:	A highly prized food fish in China Hong Kong SAR live fish markets.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Little is known about the biology and ecology of this species. Usually caught by hand-lining over rock strata. Listed as endangered by IUCN Grouper And Wrasse Specialist Group.

Source: Modified from FishBase (Froese and Pauly, 2007).



Epinephelus amblycephalus (Bleeker 1857)

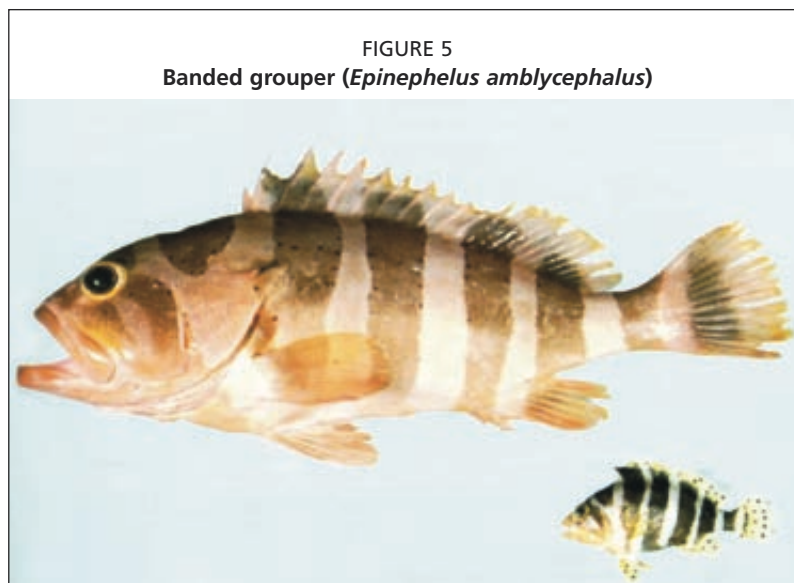
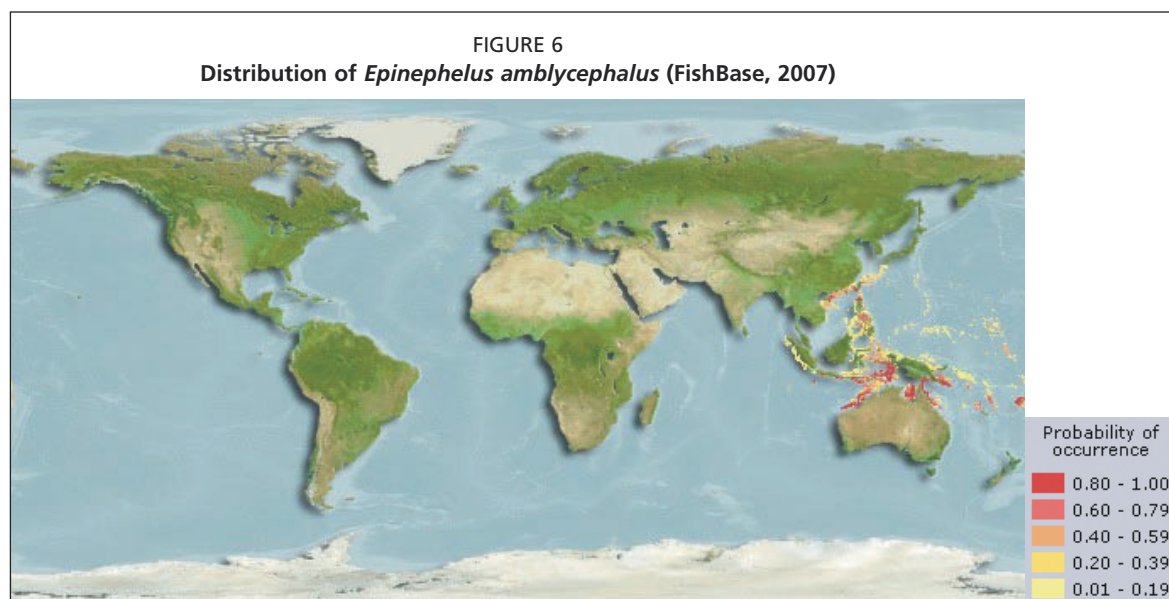


TABLE 3
Characteristics of the banded grouper, *Epinephelus amblycephalus*

Common names:	Banded grouper
Size and age:	50.0 cm TL
Environment:	Reef-associated; marine; depth range 80–130 m
Climate:	Tropical; 35°N - 20°S, 95°E - 179°W
Importance:	Fisheries: minor commercial.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Little known.

Source: Modified from FishBase (Froese and Pauly, 2007).

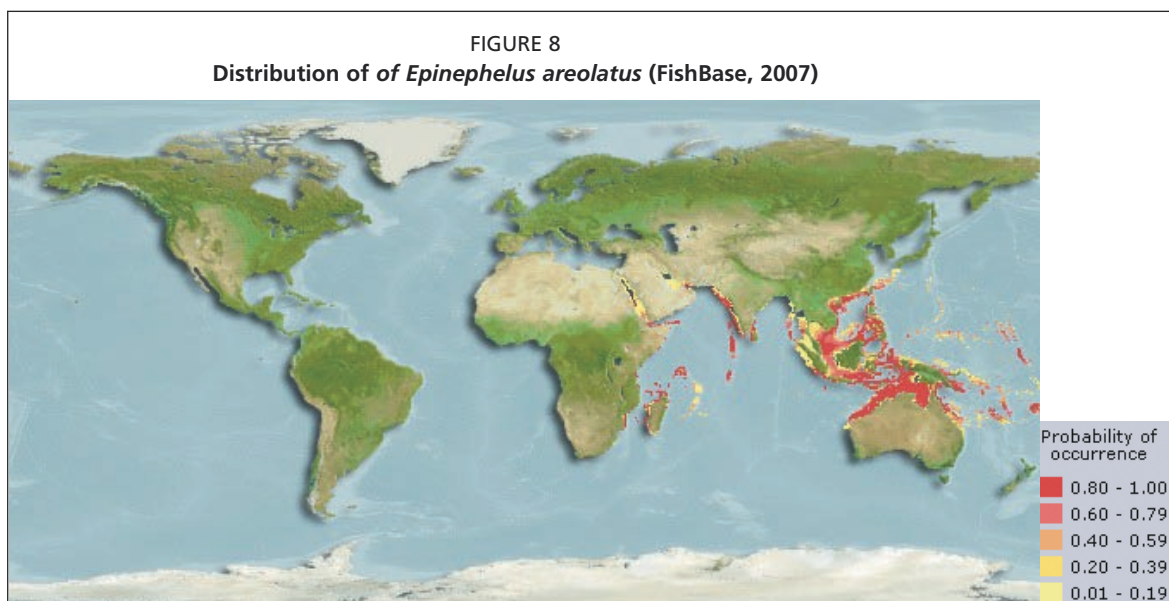


Epinephelus areolatus (Forsskål, 1775)

TABLE 4
Characteristics of the areolate grouper, *Epinephelus areolatus*

Common names:	Areolate grouper
Size and age:	47.0 cm TL; max. published weight: 1 400 g; max. reported age: 15 years
Environment:	Reef-associated; marine; depth range 6–200 m
Climate:	Tropical; 35°N - 33°S, 29°E - 180°E
Importance:	An important fisheries and aquaculture species in the Live Reef Fish Trade (LRFT).
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Usually found in seagrass beds or on fine sediment bottoms near rocky reefs, dead coral, or alcyonarians, in shallow continental shelf waters. Juveniles are common at water depths to 80 m. Probably spawn during restricted periods and form aggregations when doing so. Eggs and early larvae are probably pelagic. Feed on fish and benthic invertebrates, primarily prawns and crabs.

Source: Modified from FishBase (Froese and Pauly, 2007).



Epinephelus awoara (Temminck & Sclegel 1842)

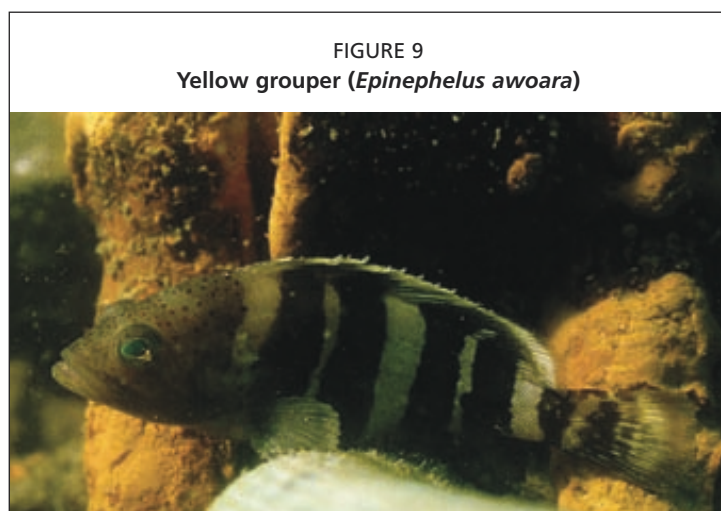
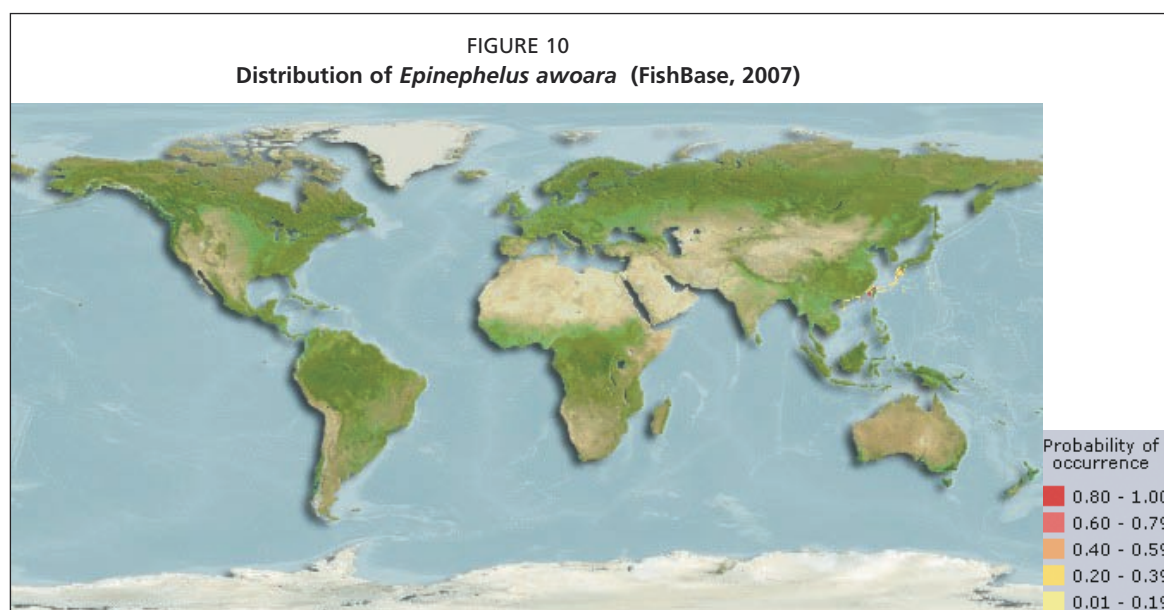


TABLE 5
Characteristics of the yellow grouper, *Epinephelus awoara*

Common names:	Yellow grouper
Size and age:	60.0 cm TL
Environment:	Reef-associated; marine; depth range 10–50 m
Climate:	tropical; 39°N - 12°N, 110°E - 143°E
Importance:	Commercial fisheries and aquaculture; medium value in China Hong Kong SAR live fish markets.
Resilience:	High, minimum population doubling time less than 15 months (Fecundity = 24 329).
Biology and ecology:	Occurs in rocky areas as well as on sandy-mud bottoms. Juveniles are common in tide pools. In captivity, the species is aggressive, chasing and biting other species, especially members of its own species. Protogynous hermaphrodite. Artificial fertilization of eggs was done and the longest survival time for the larvae was 15 days.

Source: Modified from FishBase (Froese and Pauly, 2007).



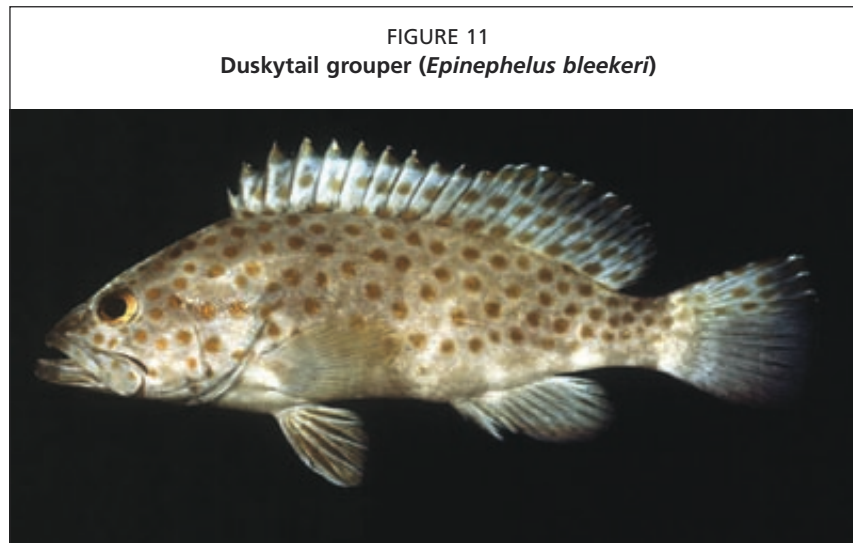
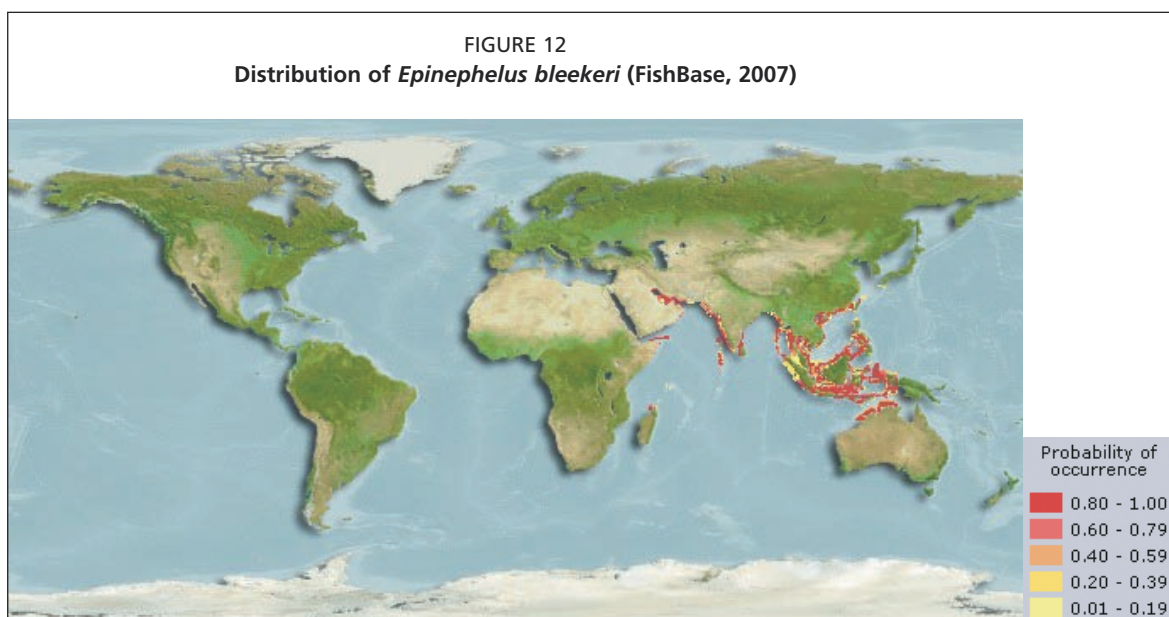
Epinephelus bleekeri (Temminck & Sclegel 1842)

TABLE 6
Characteristics of the duskytail grouper, *Epinephelus bleekeri*

Common names:	Duskytail grouper
Size and age:	76.0 cm TL
Environment:	Demersal; marine; depth range 30–104 m
Climate:	Tropical; 32°N - 17°S, 48°E - 136°E
Importance:	Minor commercial fisheries value, moderate commercial aquaculture value. In China Hong Kong SAR live fish markets.
Resilience:	Low, minimum population doubling time 4.5–14 years (t max=24).
Biology and ecology:	Occurs on shallow banks, but is not known from well-developed coral reefs. Usually taken by trawling in 30–45 m or by hand-lining over rocky banks.

Source: Modified from FishBase (Froese and Pauly, 2007).



Epinephelus bruneus (Bloch, 1793)

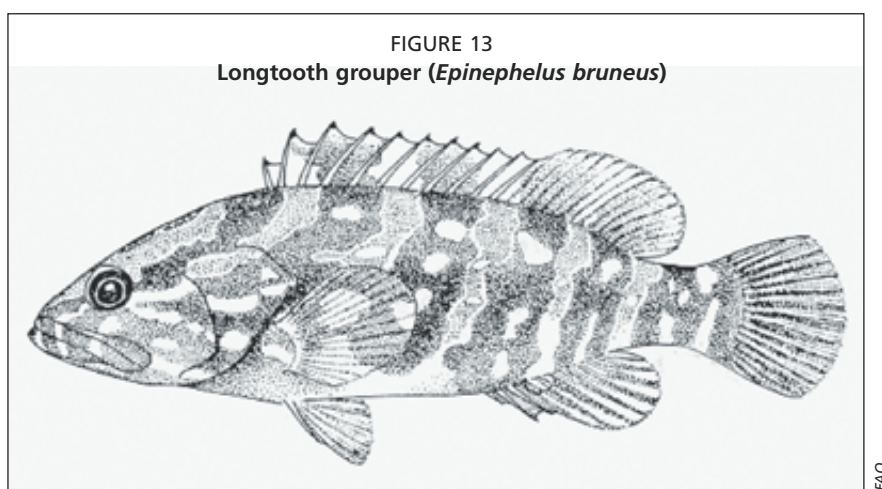
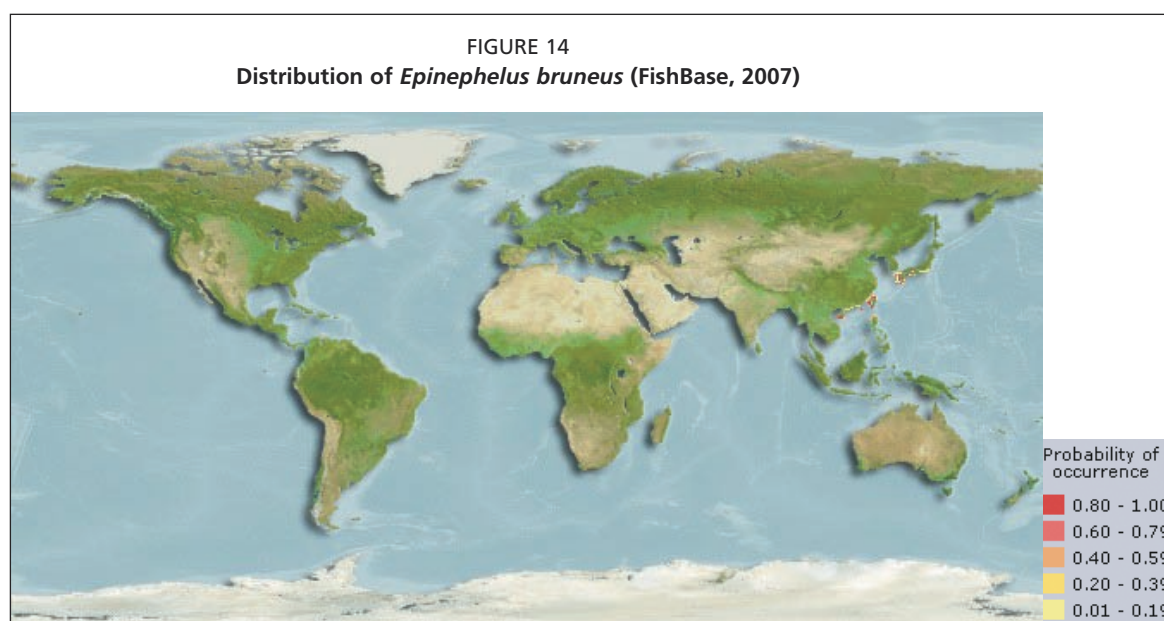


TABLE 7
Characteristics of the longtooth grouper, *Epinephelus bruneus*

Common names:	Longtooth grouper
Size and age:	128 cm TL (male/unsexed; Ref. 40637); max. published weight: 33.0 kg (Ref. 40637)
Environment:	Reef-associated; marine; depth range 20–200 m
Climate:	Tropical; 38°N - 17°N, 108°E - 142°E
Importance:	Important in commercial and recreational fisheries. Commercially cultured in Japan and China Hong Kong SAR.
Resilience:	Very low, minimum population doubling time more than 14 years.
Biology and ecology:	Inhabits rocky reefs; also found on muddy grounds. Juveniles occur in shallow waters.

Source: Modified from FishBase (Froese and Pauly, 2007).



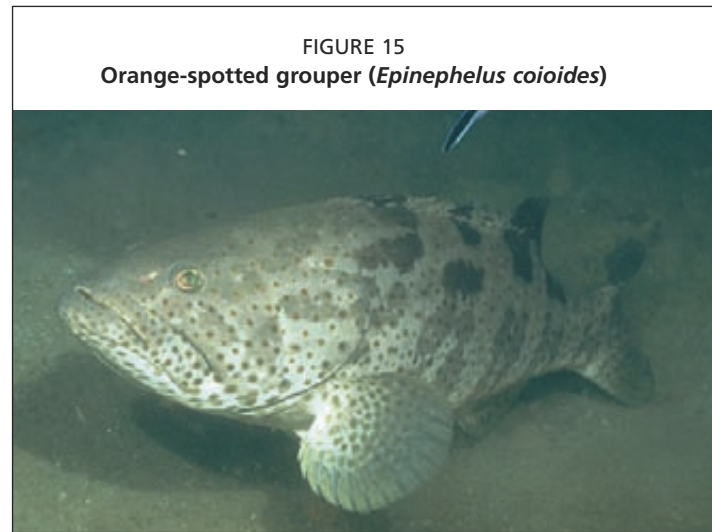
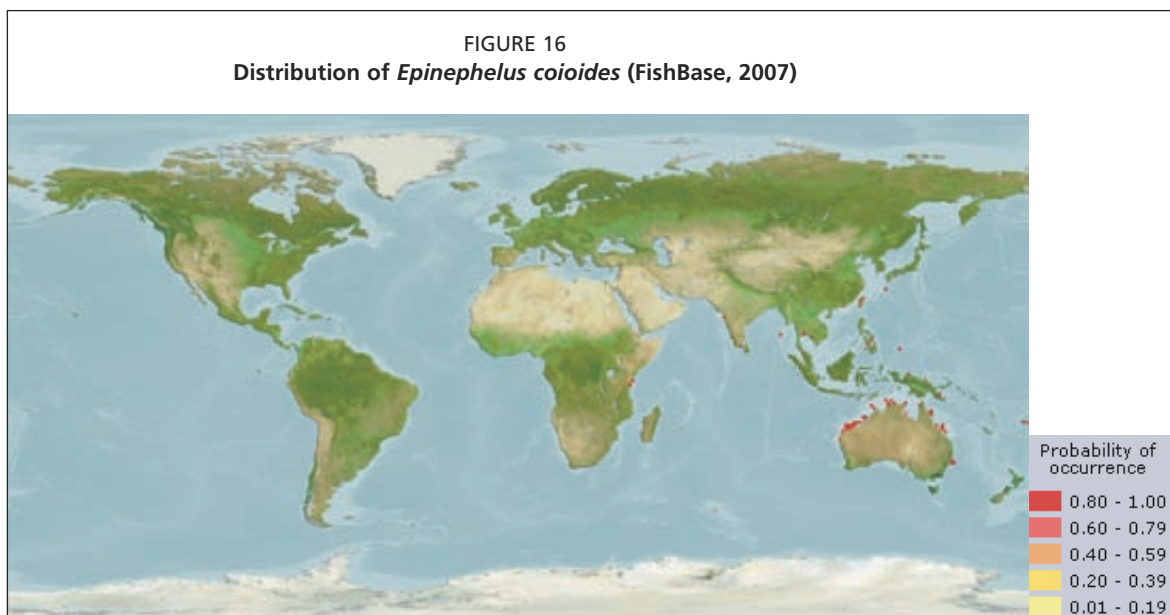
Epinephelus coioides (Hamilton, 1822)

TABLE 8
Characteristics of the orange-spotted grouper, *Epinephelus coioides*

Common names:	Orange-spotted grouper, estuary grouper, green grouper
Size and age:	120 cm TL (male/unsexed; Ref. 47613); max. published weight: 15.0 kg (Ref. 11228); max. reported age: 22 years
Environment:	Reef-associated; brackish; marine; depth range 2–100 m
Climate:	Subtropical; 37°N - 34°S, 28°E - 180°E
Importance:	Important for commercial fisheries and aquaculture throughout Southeast Asia; major species in China Hong Kong SAR live fish markets.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years ($K=0.17$; $t_{max}=22$).
Biology and ecology:	Inhabit turbid coastal reefs and are often found in brackish water over mud and rubble. Juveniles are common in shallow waters of estuaries over sand, mud and gravel and among mangroves. Feed on small fishes, shrimps, and crabs. Probably spawn during restricted periods and form aggregations when doing so. Eggs and early larvae are probably pelagic.

Source: Modified from FishBase (Froese and Pauly, 2007).



Epinephelus fuscoguttatus (Forsskål, 1775)

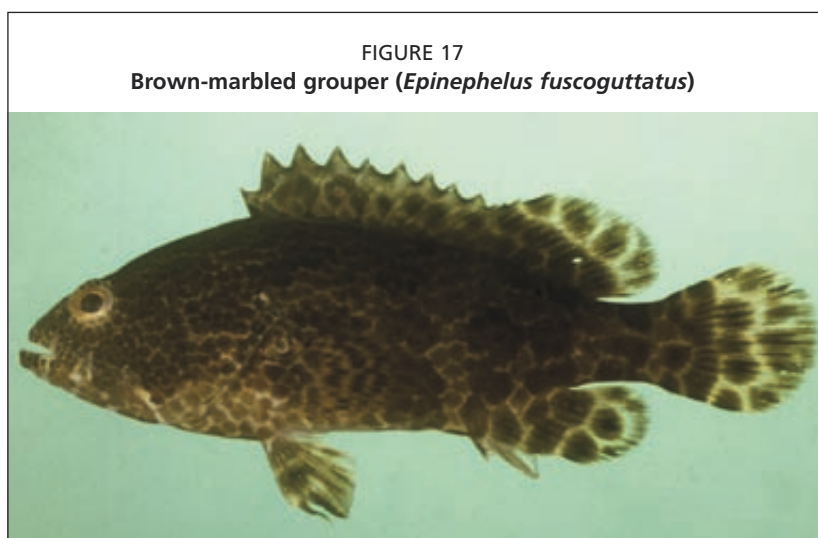
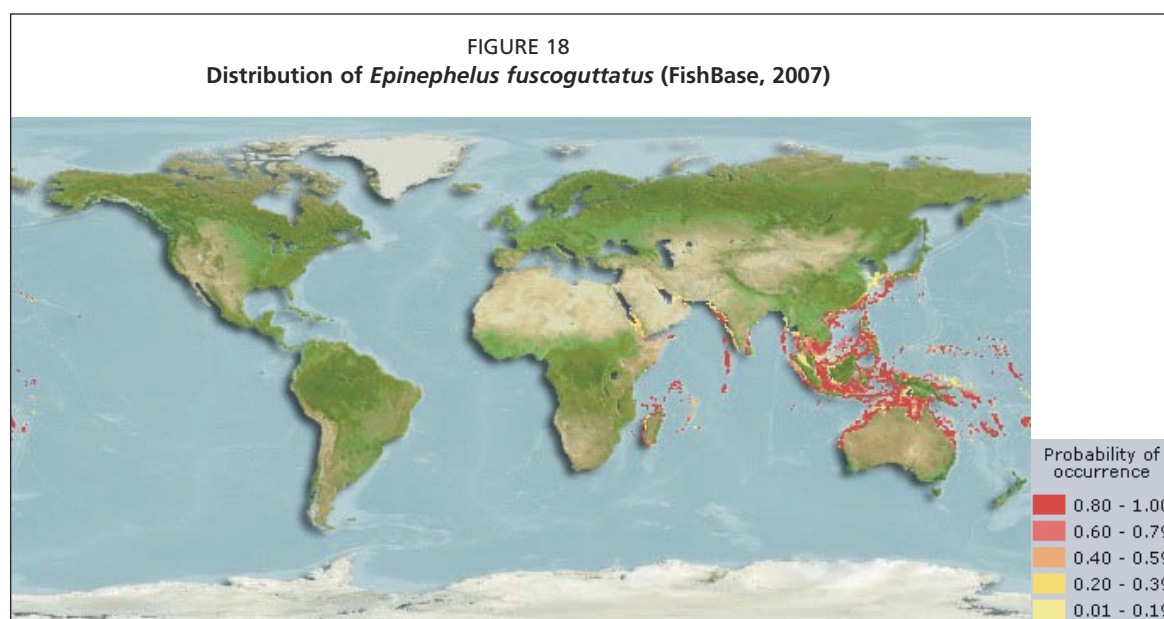


TABLE 9
Characteristics of the brown-marbled grouper, *Epinephelus fuscoguttatus*

Common names:	Brown-marbled grouper, tiger grouper, dusky grouper, flowery grouper, flowery cod
Size and age:	120 cm TL; max weight 35.0 kg, max. age >40 years
Environment:	Reef-associated; marine; depth range 1–60 m
Climate:	Tropical; 35°N - 27°S, 39°E - 171°W
Importance:	Minor commercial fisheries, moderate importance in aquaculture and live reef fish trade. Cultured in Singapore, Philippines and Indonesia.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years (K=0.16-0.20).
Biology and ecology:	Occurs in lagoon pinnacles, channels, and outer reef slopes, in coral-rich areas and with clear waters. Juveniles in seagrass beds. Feeds on fishes, crabs, and cephalopods. May be ciguatoxic in some areas. Mainly active at dusk.

Source: Modified from FishBase (Froese and Pauly, 2007).



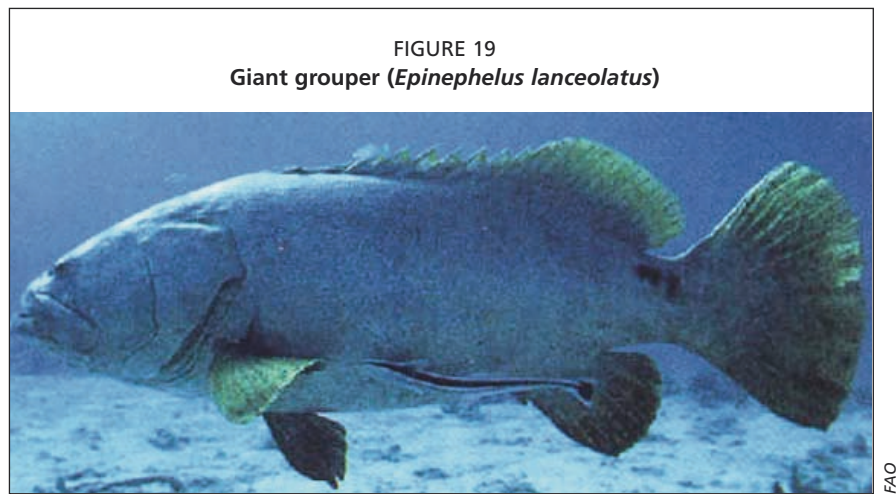
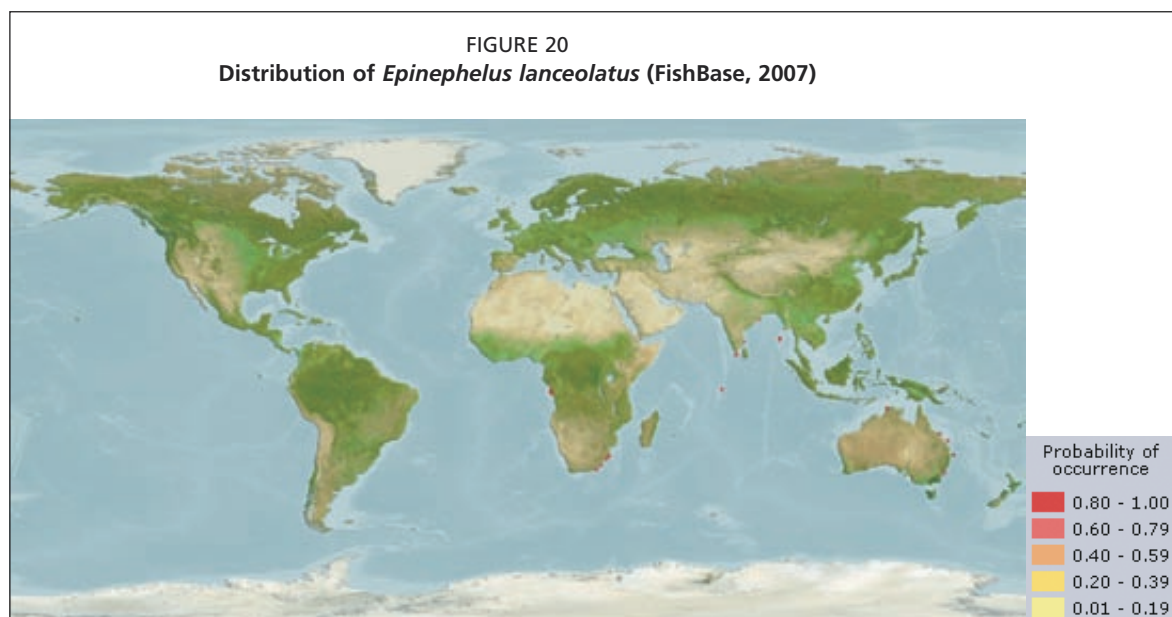
Epinephelus lanceolatus (Bloch, 1790)

TABLE 10

Characteristics of the giant grouper, *Epinephelus lanceolatus*

Common names:	Giant grouper, Queensland grouper
Size and age:	270 cm TL; max. published weight: 455.0 kg
Environment:	Reef-associated; brackish; marine; depth range 1–100 m
Climate:	Tropical; 28°N - 39°S, 24°E - 122°W
Importance:	Important in subsistence fisheries, commercial aquaculture, recreational gamefish. Cultured in Taiwan PC. In live reef fish markets. Juveniles sold in ornamental trade as “bumblebee grouper”.
Resilience:	Very low, minimum population doubling time more than 14 years.
Biology and ecology:	The largest bony fish found in coral reefs. Common in shallow waters. Found in caves or wrecks; also in estuaries, from shore and in harbours. Juveniles secretive in reefs and rarely seen. Feeds on spiny lobsters, fishes, including small sharks and batoids, and juvenile sea turtles and crustaceans. Nearly wiped out in heavily fished areas. Large individuals may be ciguatoxic.

Source: Modified from FishBase (Froese and Pauly, 2007).



Epinephelus malabaricus (Bloch and Schneider, 1801)

FIGURE 21
Malabar grouper (*Epinephelus malabaricus*)



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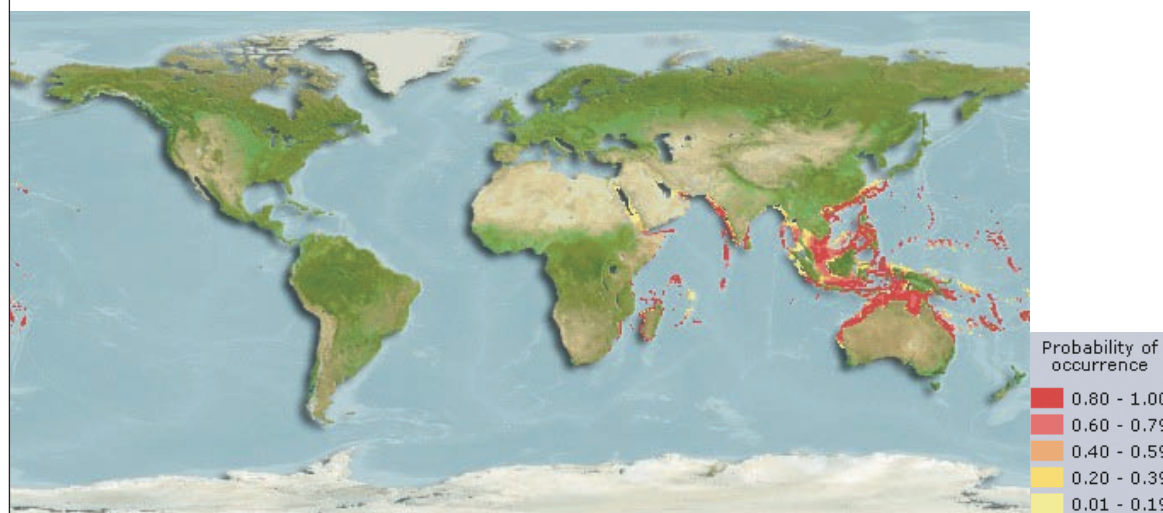
TABLE 11

Characteristics of the Malabar grouper, *Epinephelus malabaricus*

Common names:	Malabar grouper, estuary grouper, green grouper
Size and age:	234 cm TL; max. published weight: 150.0 kg
Environment:	Reef-associated; amphidromous; brackish; marine; depth range 0–150 m
Climate:	Tropical; 30°N - 32°S, 29°E - 173°W
Importance:	High value commercial and recreational fisheries and aquaculture. Cultured throughout Asia. Along with <i>E. coioides</i> , the most common species in live reef fish markets.
Resilience:	Very low, minimum population doubling time more than 14 years. Listed as Near Threatened (NT) by the IUCN Grouper and Wrasse Specialist Group.
Biology and ecology:	A common species found in a variety of habitats: coral and rocky reefs, tide pools, estuaries, mangrove swamps and sandy or mud bottom from shore to depths of 150 m. Juveniles found near shore and in estuaries; sex reversal probable. Feeds primarily on fishes and crustaceans, and occasionally on cephalopods.

Source: Modified from FishBase (Foese and Pauly, 2007).

FIGURE 22
Distribution of *Epinephelus malabaricus* (FishBase, 2007)



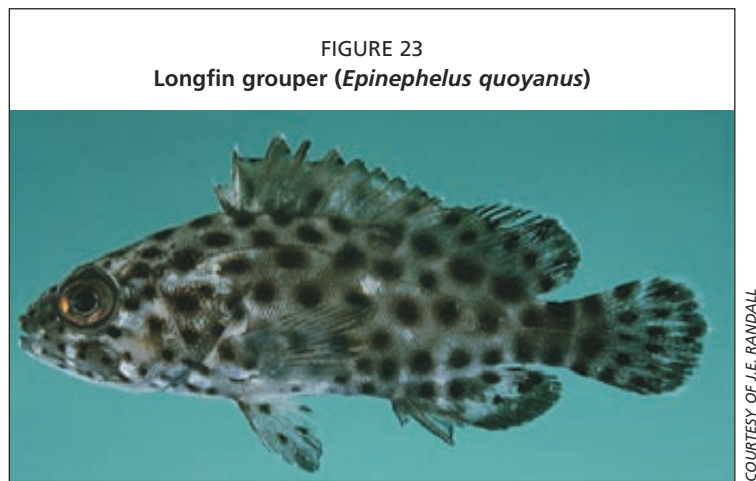
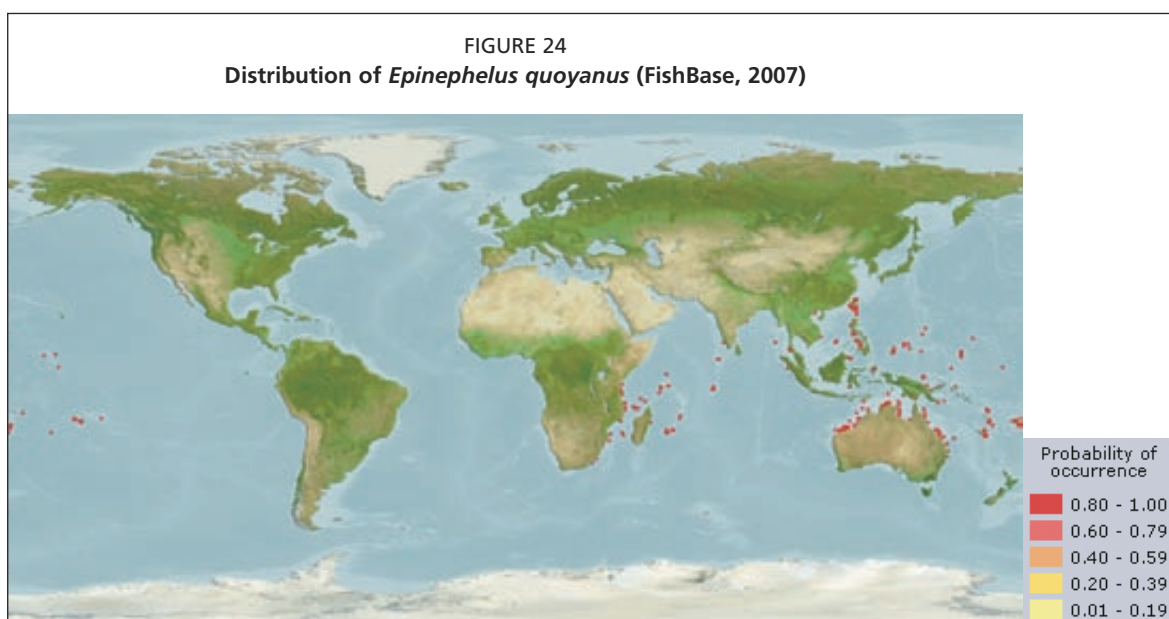
Epinephelus quoyanus (Valenciennes, 1830)

TABLE 12
Characteristics of the longfin grouper, *Epinephelus quoyanus*

Common names:	Longfin grouper
Size and age:	40.0 cm TL
Environment:	Reef-associated; marine; depth range 0–50 m
Climate:	Tropical; 35°N - 32°S, 110°E - 156°E
Importance:	Commercial fisheries and minor aquaculture; in China Hong Kong SAR live fish markets.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Inhabits inshore silty reefs; there are no records from depths greater than 50 m. Feeds on crustaceans, fishes, and worms. The enlarged fleshy pectoral fins appear to have resulted from its habit of sitting on the substrate.

Source: Modified from FishBase (Froese and Pauly, 2007).



Epinephelus sexfasciatus (Valenciennes, 1828)

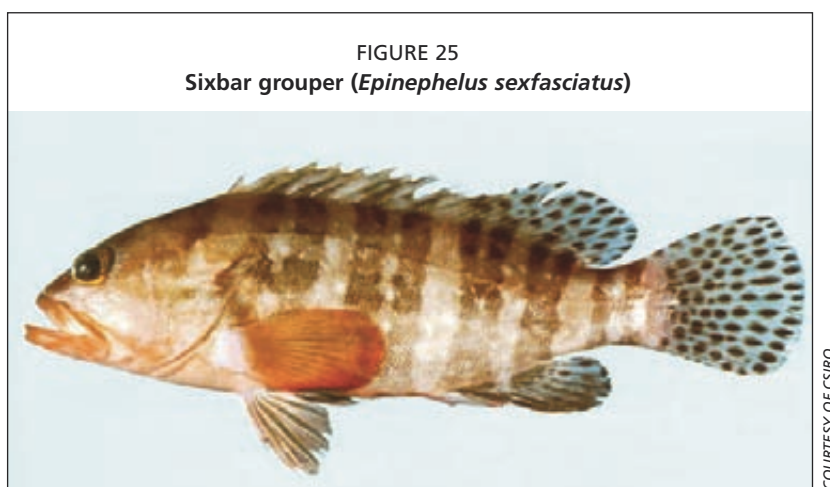
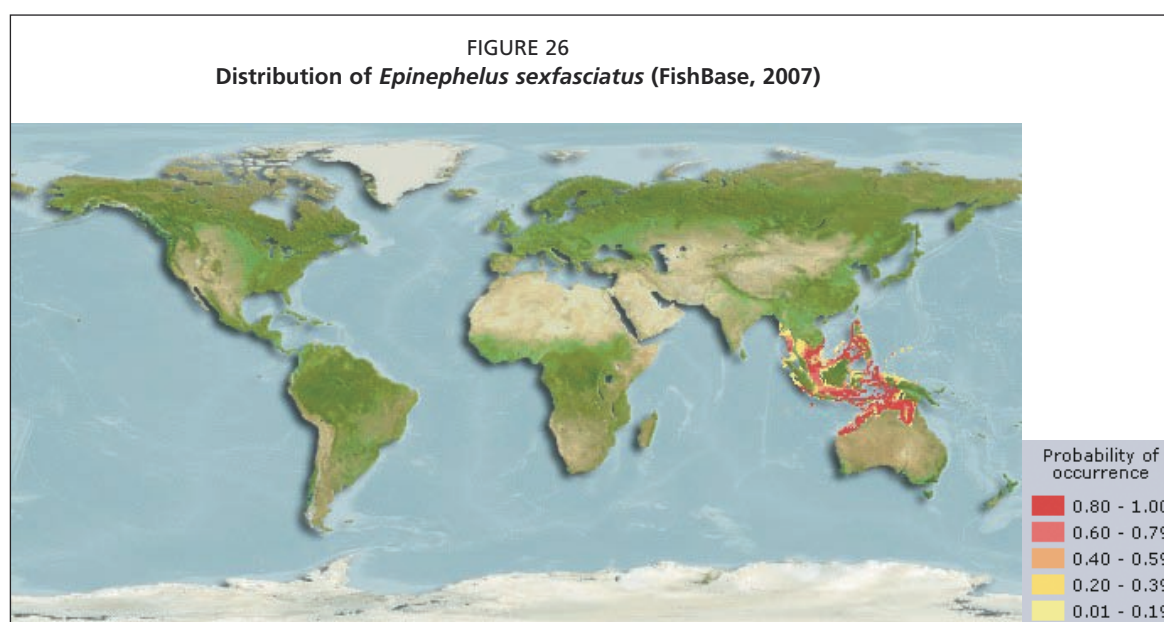


TABLE 13
Characteristics of the sixbar grouper, *Epinephelus sexfasciatus*

Common names:	Sixbar grouper, six-banded grouper
Size and age:	40.0 cm TL
Environment:	Reef-associated; marine; depth range 10–80 m
Climate:	Tropical; 21°N - 21°S, 94°E - 143°E
Importance:	Fisheries: commercial.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years (K=0.16).
Biology and ecology:	Common on silty sand or mud bottoms. Its preference for soft-bottom habitats may account for its restricted distribution and absence at oceanic islands. Feeds on small fishes and crustaceans.

Source: Modified from FishBase (Froese and Pauly, 2007).

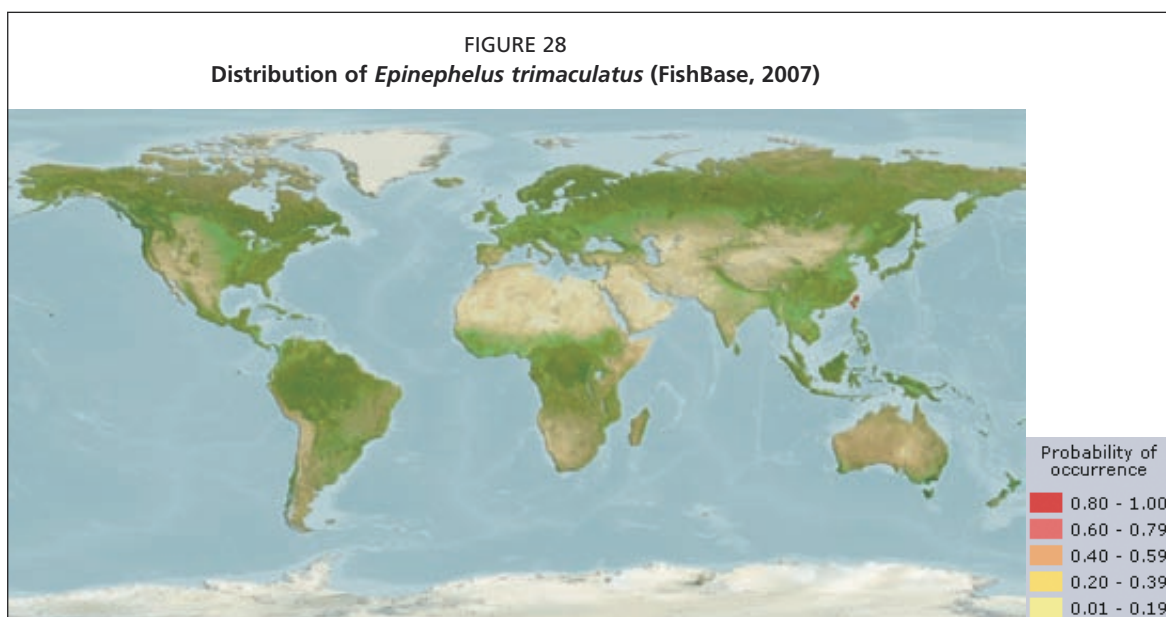


Epinephelus trimaculatus (Valenciennes, 1828)

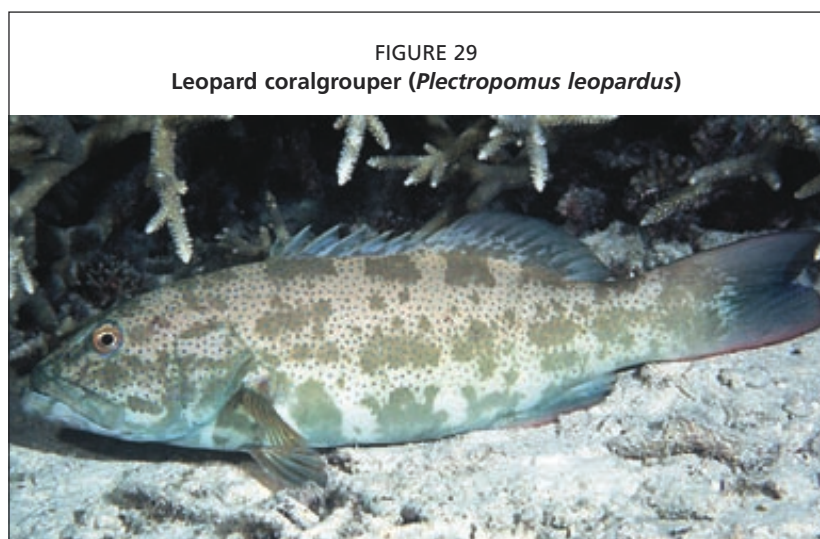
TABLE 14
Characteristics of the threespot grouper, *Epinephelus trimaculatus*

Common names:	Threespot grouper
Size and age:	40.0 cm SL
Environment:	Reef-associated; marine
Climate:	Tropical; 37°N - 20°N, 112°E - 143°E
Importance:	Commercial fisheries and minor aquaculture. In China Hong Kong SAR live fish markets.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years.
Biology and ecology:	Juveniles are common in tide pools and in shallow clear water around rocks and coral reefs; adults found in deeper water.

Source: Modified from FishBase (Froese and Pauly, 2007).



Plectropomus leopardus (Lacepède, 1802)

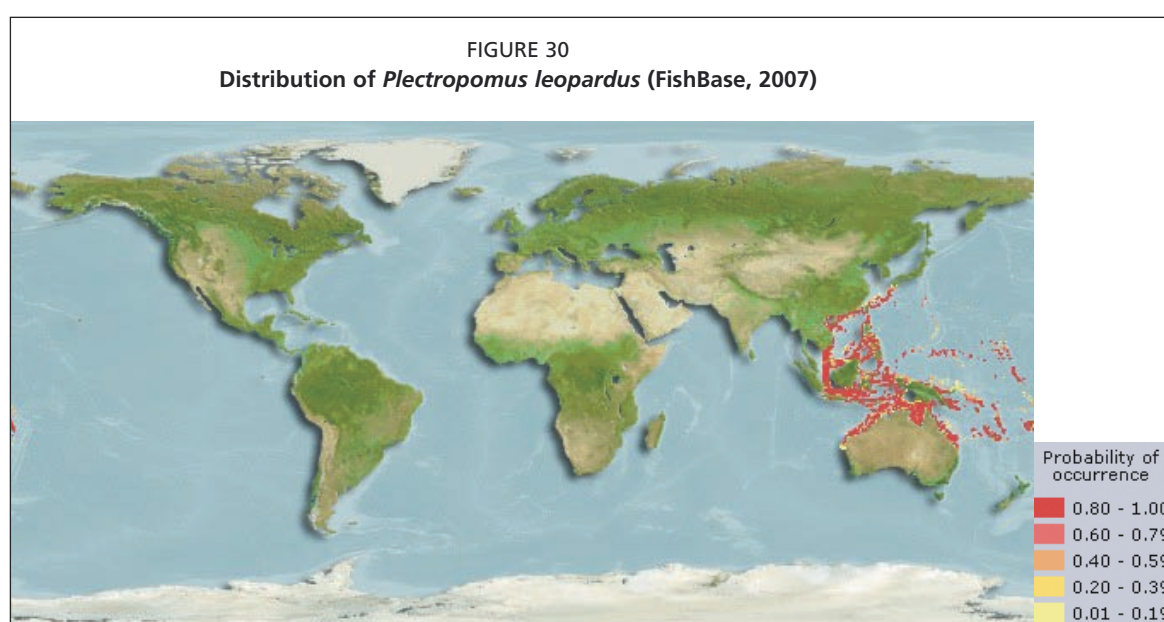


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TABLE 15
Characteristics of the leopard coral grouper, *Plectropomus leopardus*

Common names:	Leopard coral grouper, coral trout
Size and age:	120 cm SL; max. published weight: 23.6 kg; max. reported age: 26 years. On the Great Barrier Reef, lifespan is 14 years.
Environment:	Reef-associated; marine; depth range 3–100 m
Climate:	Tropical; 24; 35°N - 30°S, 106°E - 178°W
Importance:	Commercial and recreational fisheries and aquaculture, juveniles in ornamental trade.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years (tm = 2–4; tmax = 26; Fecundity = 457 900). Listed as Near Threatened by IUCN Grouper and Wrasse Specialist Group.
Biology and ecology:	Inhabit coral-rich areas of lagoon reefs and mid-shelf reefs. Juveniles in shallow water in reef habitats, especially around coral rubble. Adults piscivorous. Juveniles feed on small fish and invertebrates such as crustaceans and squid. A protogynous hermaphrodite forming spawning aggregations on a reef around the new moon.

Source: Modified from FishBase (Froese and Pauly, 2007).



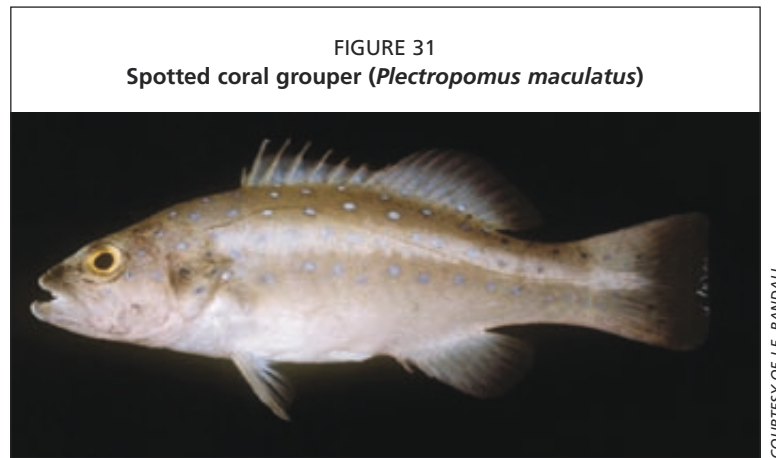
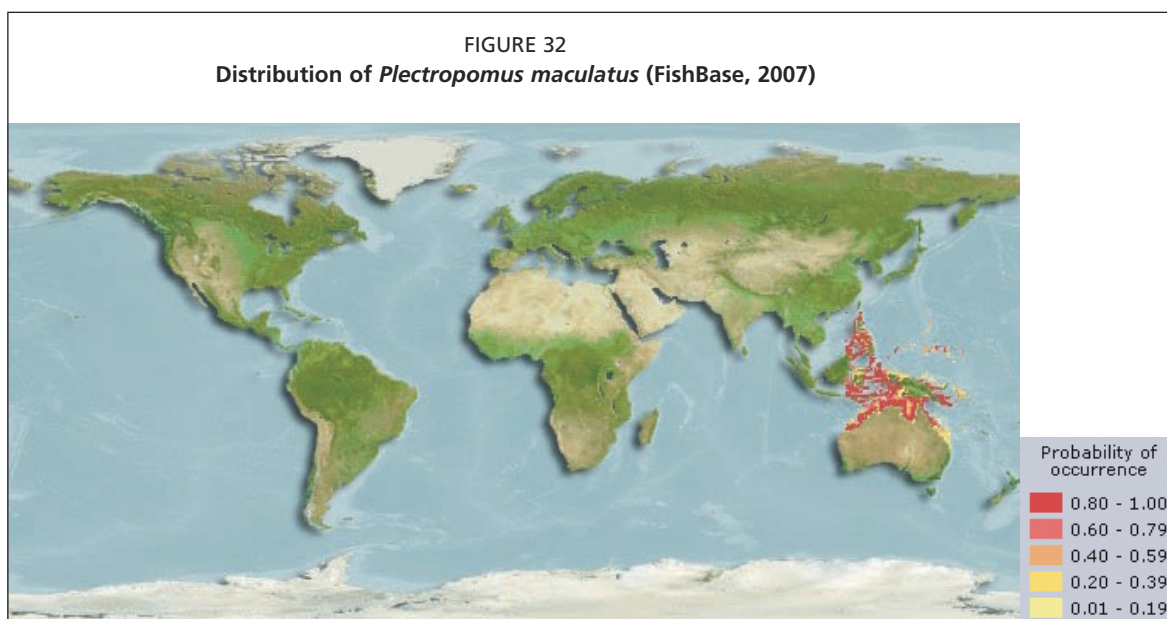
Plectropomus maculatus (Bloch, 1790)

TABLE 16
Characteristics of the spotted coral grouper, *Plectropomus maculatus*

Common names:	Spotted coral grouper, spotted coral trout
Size and age:	100.0 cm SL; max. published weight: 25.0 kg
Environment:	Reef-associated; marine; depth range 5–100 m
Climate:	Tropical; 21°N - 28°S, 117°E - 159°E
Importance:	Commercial and recreational fisheries and aquaculture. In China Hong Kong SAR live fish markets. Commonly used for food. Its flesh is delicate and well appreciated.
Resilience:	Medium, minimum population doubling time 1.4–4.4 years ($K=0.21$; $t_m=2-3$).
Biology and ecology:	Found in protected coastal reef in mixed algae and coral habitat Common on inshore coastal reefs but absent in clear offshore reefs. Juveniles in shallow water in reef habitats, especially around coral rubble. Migrate over short distances to spawn, forming aggregations.

Source: Modified from FishBase (Froese and Pauly, 2007).



Trends in production of cultured grouper

Groupers are cultured in many Southeast Asian countries, including Indonesia, Malaysia, Philippines, Taiwan Province of China, Thailand, China Hong Kong SAR, the southeast of China and Viet Nam (Sadovy, 2000). Grouper culture is also undertaken in India, Sri Lanka, Kingdom of Saudi Arabia, Republic of Korea, Australia, the Caribbean as well as in the southeastern United States of America.

Despite the huge popularity of live fish in China and Southeast Asia, only 15–20 percent of the amount consumed each year comes from aquaculture, as culture is principally constrained by limited and unreliable supplies of wild seed and the difficulties of spawning in captivity. However, hatchery production has increased in recent years (e.g. Taiwan Province of China and Kuwait) (Tucker, 1999). It is difficult to get accurate statistics on farmed grouper production because statistics do not differentiate between those simply being caught from natural sources and held for a few weeks in cages before being sold, and those cultured for a longer period of time (Ottolenghi *et al.*, 2004).

Grouper production through aquaculture is mainly reported by countries in Asia, where over 9 300 tonnes were produced in 2000. The actual figures of grouper production in Southeast Asia are reported by Sadovy (2000) to be far higher, at 23 000 tonnes; however, about 20 percent of this production may be based on hatchery produced fry, while the remainder is from wild seed. Kongkeo and Phillips (2002) estimated Asian production to be around 15 000 tonnes. In each case, these figures are significantly higher than the official statistics published by FAO. According to official statistics, Taiwan Province of China was the leading producer, with nearly 5 100 tonnes (54 percent of the global total). A total of 7 200 tonnes was produced in brackish water in Taiwan Province of China, Malaysia and Thailand. The remaining production was from mariculture a total of 2 100 tonnes, mainly in Indonesia, China Hong Kong SAR and Taiwan Province of China.

Grouper culture systems

There are many different systems used for the culture of groupers worldwide, although there seems to be an agreed set of stages: nursery, transition, and on-growing (Ottolenghi *et al.*, 2004). Grouper seed must be nursed before being cultured to marketable size. The nursery stage is reared either in tanks, net cages and *hapas* (nylon netting enclosures), or in earthen ponds. Grading is a prerequisite to minimize cannibalism, especially in the nursery and early grow-out stages. After nurseries, there are two main systems used for on-growing: pond culture or cage culture. The stocking density and rearing conditions in both nursery and grow-out phases vary, depending on the site, the fish sizes, and the grouper species cultured.

Wild fry (2.5–7.2 cm) or fingerlings (7.5–12 cm) may initially be held in tanks or net cages or earthen ponds for a month or more (nursing period) after harvest (Ottolenghi *et al.*, 2004). The density may range from 100 to 150 fish/m², e.g. a net of 2 x 2 x 2 m would hold 400–600 fingerlings. Sorting is undertaken weekly and stock sampling every 2 weeks. Groupers are normally retained in the nursery until they reach about 16 cm, when they are thinned out and transferred to transition nets (5 x 5 x 5 m) that each hold 1 100 fish. The fish are finally transferred to production nets after 2–3 months. Floating cages are often constructed from bamboo poles and polyethylene netting material (25–50 mm mesh size). Net cages are formed by two types of panels: 4 side panels forming the walls, and one bottom panel. The net is secured to the raft structure (bamboo poles) by ropes. Ropes are also used to lash the bamboo poles together. Buoyancy is provided by empty plastic containers attached to the bamboo frames (www.seafdec.org.ph). Net cages come in several sizes (3 x 3 x 2.5 m; 4 x 4 x 2.5 m; 10 x 10 x 3 m); the mesh size ranges from 10 to 35 mm (Agbayani, 2002). The optimum stocking density averages 120 fish/m³. Growth to marketable size (600–800 g) takes

approximately 8 months, with survival rates of 50 percent or less. Groupers can grow to 600 g in 12 months, to 1 kg within 18 months, and to 2 kg within 24 months (Tucker, 1999).

Harvesting of groupers is relatively simple (Ottolenghi *et al.*, 2004). Selective harvesting of groupers weighing 400–600 g is best. A drag net is placed at the farthest end of the pond or cage, and dragged slowly towards the other end in the early morning. Fish are then transferred to a holding net where grading is carried out; undersized fish are returned to the pond or cage.

FISHERIES FOR JUVENILE GROUPER

Collection of grouper seed

Grouper seed is collected using several different methods, depending on location (Table 17). Capture methods are generally artisanal and the fishermen employ a variety of artificial habitats. Moreover, different fishing gears are used at different times of the year: the gear change follows the growth of the seed and their movement to deeper waters as the season progresses. Gears used to take grouper seed can be divided into 8 different categories: large fixed nets (e.g. fyke nets), traps and shelters, hook and line, scoop and push nets, artificial reefs, fish attractors, tidal pools and chemicals. The sizes of grouper seed caught and traded vary between 1 and 25 cm, i.e. from the moment of settlement to fish that are over one year old. However, most of the catch focuses on fish up to about 15 cm (Sadovy, 2000).

Some grouper seed collection methods are more damaging than others. Clearly destructive methods include those that result in high mortality, involve high levels of

TABLE 17
Overview of seed collection methods for capture-based aquaculture of groupers in Southeast Asia

Gear type	Description	Location	Fish size (cm)
Gango (fish nests)	Conical pile of waterlogged, criss-crossed wood or of rocks, sometimes in combination, together with old car tires, PVC pipe cuttings, bamboo sections, or other shelter materials. Covers 5–10 m ² , with a 2–3 m diameter or 2.5–3x2–3 m base and 0.5–1.5 m height. The largest may be 5 m diameter at the base.	Philippines	2–15 cm
Fish shelters	Formed by hanging brushes, nets or clusters of grasses, leaves or other materials. Used with or without lights.	Philippines China Thailand	1–3 cm
Fish traps	Vary in shape and size, and in mesh size. The trap frame is made of metal, wood or bamboo.	Indonesia Malaysia Philippines China Taiwan PC Viet Nam	2–25 cm
Fyke net	Big collectors, stationary nets installed in river mouths during high tides. Three mesh sizes are used: larger at the aperture, followed by medium and finer net at the end.	Philippines Thailand Viet Nam	1–15 cm
Hook and line		Indonesia Malaysia Philippines China Taiwan PC Thailand Viet Nam	>7.5 cm
Scissor net	A triangular bamboo frame of various dimensions, which may or may not have “shoes” to assist it in moving over the substrate. Fine meshed netting is attached to the frame and the bamboo poles are crossed over each other.	Philippines Thailand	2.5–15 cm
Miracle hole	Shallow holes are excavated on tidal flats. Sometimes the wall of the hole is built up with rocks.	Philippines	5–10 cm
Temarang	Artificial aggregating device (fish shelter), which consists of a bunch of twigs from wild shrubs; about 20–30 bunches of 50 cm length are tied to a 5 m rope and hung over sandy sea bottom between two poles.	Malaysia	2–2.5 cm

Source: Modified from Ottolenghi *et al.*, 2004.

bycatch, cause damage to the fish habitat and/or result in monopolization of the local fishery by a few individuals. Destructive methods include scissor nets and fyke nets, which are already banned in some areas. Lift nets are also destructive, particularly in terms of bycatch. Gangos, miracle holes and other types of artificial shelters and seed aggregation devices do not possess the above drawbacks. Methods that target postlarvae seem less likely to deplete wild stocks because of the high natural mortality that probably characterizes this stage in the wild (Johannes and Ogburn, 1999; Sadovy, 2000).

Mortality rates from catching to stocking

Seed quality depends on the type of fishing gears used, and there are significant differences in seed mortality rates. Mortality rates associated with fish traps are usually low. For example, the use of “*Bubu*” (fish traps used in Malaysia) cause a 5 percent mortality rate, while artificial aggregators such as *Temarang* (also used in Malaysia) cause 3 percent mortality. Other catching methods, like scissor nets and fyke nets, can generate a high mortality. “*Pompang*” (fyke net) and “*Wunron*” (push/scissor net), which are used in Thailand, are reported to cause 20–30 percent and 80 percent mortality rates, respectively (Sadovy, 2000). It is likely that subsequent mortalities during transport and stocking will also be high, as many of the seed fish will also have been damaged, and are therefore susceptible to stress and disease.

The problems that arise during seed transport to the net cages or to the middleman/farmer/exporter, depend on seed size, quality, fitness and the locality. For transport over short distances, in Thailand, for example, “seeds” are placed in styrofoam boxes or buckets, with or without aeration (often provided by middlemen), or with holes in the bottom for water exchange.

Transport time is typically from about 10 minutes up to two hours. Post-harvest mortality is low. For longer transit periods, fish are packed in 23–25°C seawater with aeration. Transport densities are about fifty 7.5 cm fish per bag, or one hundred 1 cm fish/l, or two to three hundred 3–7.5 cm fish per bucket. For a 7-hour journey, ice can be used to keep the water cool. Some exporters use an anaesthetic, either quinaldine or MS222, but consider the latter to be rather expensive. The use of anaesthetic is considered important to reduce the likelihood of spines piercing the plastic transport bag. For export, fish are packed into styrofoam boxes of various sizes; each shipment has about 20 000 fish in 30 boxes (Sadovy, 2000).

In the Philippines, approximately 10 percent of the seed caught is used domestically, while the remainder is exported. There can be significant mortalities during local transportation. The movement of seed from the catchers to the middlemen or the farmers is carried out by keeping fish in plastic containers or basins with holes for water circulation. Mortality rates are quite low under such circumstances. If destined for trade, the fish may be maintained for short periods by the middleman, prior to packing and shipping, either domestically or internationally. In some cases, they may be transferred temporarily (for a few days) to an “aquarium box” to await buyers who come to collect fish and who are responsible for the export of the fry. Mortality rates can reach 10–20 percent at this stage, i.e. prior to selling to buyers for export or domestic trade (Sadovy, 2000). Mortality rates are low if the transit time is less than an hour. However, for longer periods, if there is no aeration or frequent water changes, mortality increases and oxygen may have to be added. Buyers pack fry in double plastic bags with pre-cooled water using ice (18–22°C) and a salinity of 15–18 ppt. 2.5 cm “seeds” are packed 400–500 per box and 7.5–10 cm “seeds” are packed 20–40 per box (Sadovy, 2000).

The mortality rates that follow capture and transport are not exactly known; estimates for over the first 2 months after catching are quite variable (30–70 percent), depending on the quality of fry, the level of transport stress, and the presence

of disease and cannibalism (Pudadera, Hamid and Yusof, 2002). According to a report from the Secretariat of the Pacific Community (www.spc.org.nc/coastfish/News/LRF/5/15GrouperHK.htm), the survival rate for imported fry is low, at 10–20 percent.

AQUACULTURE DEPENDENCY ON WILD SEED

Generally, groupers spawn on offshore reefs where they form aggregations of hundreds to tens of thousands of individuals, in a few specific locations (Johannes *et al.*, 1999; Rhodes and Sadovy, 2002). They produce pelagic larvae that may disperse over hundreds of kilometres in the course of 30–45 days and experience high density-independent mortality. However, recent research suggests that groupers and other reef fishes may have greater control over their distribution than previously thought, and that at least some proportion of the gametes spawned may be retained near their natal reef (Jones *et al.*, 1999; Jones, Planes and Thorrold, 2005; Swearer *et al.*, 1999). Larvae, transported to near-shore nursery habitats settle as juveniles in sea-grass beds, mangroves, algal beds, coral rubble, oyster reefs and marshes (Coleman *et al.*, 1999; Tupper, 2007). For this reason grouper seed is mainly caught in coastal areas, particularly around sea-grass, mangrove and shallow brackish water areas near river mouths and estuaries, as well as in tidal pools, tidal channels and around reefs.

The peak grouper seed season is often associated with the relatively wet months in the year (e.g. monsoon seasons); in several areas, grouper seed collectors have claimed that their best catches were associated with strong onshore winds (Johannes and Ogburn, 1999). This is consistent with a number of recent studies into recruitment pulses of settlement-stage reef fish – including groupers – that accompanied cyclonic storms, which apparently caused the fish to be transported shoreward (Shenker *et al.*, 1993; Dixon, Millich and Sugihara, 1999).

Because groupers are particularly difficult to culture in closed systems, full-cycle culture of most grouper species is not yet possible. For this reason, approximately 66–80 percent of all grouper culture involves the capture and grow-out of wild seed (Sadovy, 2000). The volume of seed caught each year exceeds hundreds of millions of individuals (Sadovy, 2000). The greatest catches tend to be of the smallest size classes (1–3 cm); during peak seasons a catch can be of tens of thousands by a single unit of gear, in a single night, by one fisherman (e.g. using a fyke net). Even larger sizes of fish are being captured in massive numbers region-wide each year. It is important to realize that the equivalent of the typical annual amount of seed produced in the hatcheries in the whole of Southeast Asia (excluding Taiwan Province of China), i.e. 20 000 to 80 000 fry, can be caught by one fisherman in one night (Sadovy, 2000).

When seed catches are compared to the numbers of marketable fish produced, the results strongly suggest crude and wasteful culture practices. Sadovy (2000) estimated that about 60 million seed fish are needed produce the regional total of 23 000 metric tonnes of table-size live fish from culture annually.

FISH FEED

As with all culture systems, there are many local variations in the feeds and feeding regimes utilized. There appears to be no universal system, and local availability seems to be the key criteria in developing a feeding schedule (Ottolenghi *et al.*, 2004). Fry and fingerlings are fed with mysids and small shrimp for a couple of days post-capture in tanks, to acclimatize them and check that all individuals are eating. Trash fish forms the main feed in nursery and production cages, which is minced or chopped to suit each size group; trash fish may be supplemented with vitamins and minerals. This kind of feed is gradually being replaced by moist pelleted feed.

Trash fish is commonly used for feeding in grouper cage culture, but its increasing cost, shortage of supply, variable quality and poor feed conversion ratios indicate that

this form of feed may not be the best from either a nutritional or an economic point of view. However, groupers fed with bycatch (trash fish) in a study by Bombeo-Tuburan, Kanchanakhan and China (2001) fared significantly better in terms of final length and total production than when fed other diets (live tilapia, formulated diet).

A major problem is the limited supply of trash fish, so there is a need to develop a suitable diet for grow-out grouper production (Millamena, 2002). Fishery products, both in the form of low value trash fish or fishmeal, are presently the major sources of protein in the grow-out culture of most fish species and constitute up to 70 percent of their dietary composition. As the demand for fishmeal and fish oil for aquaculture increases, costs are expected to rise unless new sources (e.g. fish discards, krill, mesopelagics) can be economically exploited or substitutes for these marine products for inclusion in aquafeeds prove commercially applicable (New and Wijkstrom, 2002).

A dependable supply of cost-effective, non-marine, sources of alternative protein must be provided if fish farming is to remain profitable. Millamena (2002) conducted a feeding trial to evaluate the potential of replacing fishmeal with processed animal by-product meals, meat meal and blood meal, in practical diets for juvenile groupers (*Epinephelus coioides*). The study demonstrated that up to 80 percent of fishmeal protein can be replaced by processed meat and blood meal derived from terrestrial animals with no adverse effects on growth, survival, and food conversion ratio (FCR). From an economic standpoint, replacement of fishmeal with cheaper animal by-product meals in practical diets can alleviate the problem of low fishmeal availability and high costs. These processed by-products can be delivered in the Philippines, for example, at US\$0.40/kg, less than half the price of most commercial fishmeals (US\$1/kg). The effective use of meat meal-based diets for grouper grow-out also reduces the requirements for trash fish, another fishery resource that is extensively used (Millamena, 2002). Economic sensitivity analysis showed that a combination of improvements resulted in higher return-on-investment (ROI). However, these apparently favourable results must be balanced with the fact that some countries (e.g. in the EU) have banned the inclusion of all terrestrial meat-meal based products in fish feeds, due to fears concerning mad-cow disease (Ottolenghi *et al.*, 2004).

ENVIRONMENTAL IMPACTS OF THE JUVENILE GROUPE FISHERY

Mous *et al.* (2006) conducted a pilot study in Indonesia of artificial shelters (*gangos*), to determine the sizes and capture rates of species of interest to the live fish trade, and to determine the likely environmental footprint of a gango type of capture method. From the results of the 15-month study, they drew inferences regarding the sustainability of this fishing method and requirements of space, fish and materials for a viable grow-out operation. The results showed that gangos were unselective for either species or size. Only 1.4 percent of the total fish catch (by number) were target species, mainly the grouper *Epinephelus coioides*, and most were large enough (mean total length was 13.6 cm) to have bypassed the early high mortality phase. Moreover, there were large non-target catches that included many food fish species too small to be useful in catches. Assuming that a soak-time of 3 months results in an average catch per gango of 6.6 *E. coioides* (as was observed for this species in Terang Bay, the most productive of the four sites), yearly production per gango would amount to 26.4 fish. Even a small local grow-out industry with a capacity of 25 tonnes would require an annual supply of 80 000 fish, assuming a grow-out weight of 0.6 kilogram and 50 percent mortality from fingerling stage to market-ready product. This would require deployment of an estimated minimum of 3 000 gangos.

With such figures in mind, Mous *et al.* (2006) estimated of the space needed to accommodate sufficient gango deployment and suggested that a sizeable fish culture industry based on capture of fry, fingerlings and juveniles from the wild would have a large ecological footprint. For example, the 3 000 gangos estimated to support a

25 tonnes grow-out operation, would require approximately 300 000 m² (assuming that each gango requires a plot of 10 x 10 m) or 30 kilometres of coastline (assuming that gangos are deployed in a single line following the optimum depth contour). In other words, juvenile supply would require 1.2 hectares of shallow coastal waters for each tonne produced.

Given the large number and area of gangos needed for a viable operation, and that many groupers captured could probably have survived to reproduce, the ecological footprint of this approach could be substantial (Mous *et al.*, 2006). These results, and literature on other juvenile fisheries, suggest that CBA sources of seed such as gangos may often need management, have important links to other capture fishery sectors, and require careful evaluation of potential costs and benefits before introduction or development.

Support for grouper CBA is often based on the assumption that the natural mortality of early juvenile grouper is very high, so that the fishery is not adding substantially to this natural mortality and therefore not affecting adult population size to any great extent. This assumption remains untested for grouper species. As Sadovy (2001b) points out, the critical question is how early do juvenile mortality rates decline to adult levels? If early mortality is high, then removal of some post-settlement fish for culture may have little impact on adult numbers, since the probability of survival of any individual fish is low. However, recent research suggests that the period of very high mortality occurs during and immediately after settlement, and that fish surviving more than a few days have a much higher chance of survival. Tupper (2007) estimated the cumulative mortality of early juvenile (2.5–5.0 cm TL) *Plectropomus areolatus* and *Epinephelus polyphekadion* in their preferred nursery habitats to be around 50–75 percent over the first 3 months post-settlement. Assuming an exponential rate of decline in mortality, the instantaneous mortality at 3 months post-settlement would be much lower than 50 percent. Indeed, mortality rates of post-settlement juveniles may not be substantially greater than adult mortality (estimated at 20–30 percent for most groupers, e.g. Posada and Appeldoorn, 1996) and are likely much lower than the estimates of >90 percent mortality often suggested for newly settled reef fishes. If each individual has a 50 percent chance of surviving the first 3 months after settlement, then removal of large numbers of juveniles will almost certainly have an impact on adult population size. This could result in direct conflicts with the adult capture fishery and could accelerate overfishing of groupers.

In addition to problems of bycatch, wasteful mortality, and overfishing, cage and net culture can create other environmental problems, most notably point-source pollution which can have adverse effects on coastal waters, and particularly on coral reefs. For example, in 1994, researchers in Barbados noted complete bleaching and eventual death of coral patch reefs in the vicinity of a cage culture operation for dolphin fish (*Coryphaena hippurus*). Disease transfer is another problem exacerbated by the complex and extensive trade in live fish between Asian countries.

SOCIAL AND ECONOMIC IMPACTS OF GROUPE FARMING

Despite the growing importance of grouper aquaculture as both an alternative to wild caught grouper for the LRFT, and as an alternative livelihood for fishers engaged in destructive fishing practices, relatively little is known about the social and economic impacts of grouper farming, and the broader socio-economic context in which it takes place. Studies have focused on the trade of live reef fish which fuels the fishery for grouper and provides an incentive for grouper aquaculture.

The trade in live reef fish

The trade in live reef fish, whereby fish are transported live from the capture location to restaurants and supermarkets, began in China in the 1960s when a few marine species were to be found in the live fish markets of China Hong Kong SAR, and has expanded

rapidly since the early 1990s. The preference for keeping fish alive until minutes before cooking and consumption has been popular for centuries in Chinese culture, and until recently this demand for live fish was supplied by locally caught species. A preferred species for consumption was the red grouper, *Epinephelus akaara*, until overfishing of both adults and later fingerlings for culture in China Hong Kong SAR waters led to severe depletion of local stocks, forcing fishermen and the LRFT industry further afield to seek out supplies to meet local demand for market size fish. In the mid-1970s fishing boats began to exploit Philippine waters, and later the islands of Indonesia, before moving on to the Pacific Islands (e.g. Papua New Guinea, the Solomon Islands), Australia's Great Barrier Reef, and the Maldives (Johannes and Riepen, 1995). Thailand is now also an important contributor to the LRFT. The trade supplies a luxury, niche market. Live reef fish are described as being "high-value-to-volume" and can fetch US\$5 to US\$180 per kilogram, considerably more than dead reef fish (Sadovy *et al.*, 2003). Highly valued species such as *Cheilinus undulatus*, or humphead wrasse, can fetch a price of up to US\$200 per kilogram (Lau and Parry-Jones, 1999).

China Hong Kong SAR is the hub of the live reef fish trade, and the destination for much of the wild-caught and cultured grouper in the region. Approximately 60 percent of internationally traded live reef fish are exported to China Hong Kong SAR (Sadovy and Vincent, 2002), representing approximately 15 000 to 20 000 tonnes per year at a value of US\$350 million (Muldoon and MacGilvray, 2004). Accurate volumes of trade for individual species are difficult to estimate, as exports are not disaggregated at the species level and much of the trade goes unreported (Sadovy *et al.*, 2003).

The market network linking farmers to consumers is relatively long and complex, frequently crossing international boundaries, with ownership changing repeatedly. Grouper farmers obtain fry fish from their own fish catch, purchase from local fry fishers, private or government hatcheries. It is common for fry fishers who do culture grouper to sell their catch to a middleman, who may support a group of ten to thirty fishers. The fry are then either sold locally to farmers for on-growing or transported directly to export centres for shipping to other countries in the region. Grouper from grow-out operations are also predominantly destined for the export market, although there is also a growing domestic market in many countries where grouper are becoming increasingly popular on the menus of local seafood restaurants throughout Southeast Asia.

Social impact of grouper fry fishing

The number of fishers exploiting the grouper fry resource is unknown, but estimates suggest that fry fishers in the Philippines may number in the tens of thousands (Sadovy, 2000). For these fishers, fry fishing represents one activity in a broader portfolio of activities on which they depend. Fry fishing is seasonal in nature and both fishers and non-fishers alike enter the fry fishery if market signals indicate a lucrative opportunity. Fishers may be engaged in the fishery on a full- or part-time basis, whilst also engaging in other fishing activities for the capture of food fish or fish for the aquarium trade (Sadovy, 2000). The capture of wild grouper fry is reported to make a significant economic contribution to the lives of coastal fishers (Sadovy, 2000). However, despite this apparent significance, few studies have attempted to assess the role of these wild fry fisheries in the livelihoods of coastal fishers. There is, therefore, a critical gap in our understanding of the precise nature of the contribution made by wild fry fisheries to coastal households, the economic and gender profile of fishers, and the way in which coastal fishers may be affected by developments in the grouper industry.

Some studies in the region do indicate that the capture of grouper fry may contribute substantially to household incomes. In Sulawesi, Indonesia, for example, fishers may catch in the region of 1 000–2 000 2.5 cm fry per fisher on daily basis during the peak season using scoop nets, with a value of US\$300–600 (Haylor *et al.*, 2003). In Viet

Nam, income from grouper fry/fingerling harvest was reported to earn fishers as much as US\$3 080 per year (Sadovy, 2000).

Grouper fry fishers do not represent a homogenous group in terms of social status. Fishing households, like most rural households, engage in a diverse range of activities of which fishing may be only one component. Similarly, fishing activities are also diverse with fishers using a variety of gears to target different species according to seasonality and the tides. Dependence upon fry fishing is therefore rare, if it exists at all, although the extent to which the income from fry capture contributes to the total household income will vary from household to household. The relatively high value of grouper fry compared to the rest of the fish catch may, therefore, represent an important income source. As one fisher in Viet Nam indicated, catching 5–10 grouper fry per day can equal the income from all the other fish harvested (Sadovy, 2000). Findings from a survey in Thailand suggest that, for the majority of households, fry fishing is a supplementary activity, often opportunistic, with fishers entering and leaving the fishery according to fry abundance and market signals. Fry fishing in southern Thailand complements the regular fishing activities of coastal fishers, whose principal target species, including shrimp, small pelagic species, are caught at different times of the lunar calendar. Fry fishing therefore allows fishers to supplement their fishing activities at a time when fishing would otherwise not be possible (Sheriff, 2004).

Social impacts of grouper aquaculture

Important synergies exist between grouper aquaculture and fry fishing, which blur the distinction between fry fishers and grouper farmers, and give added significance to the role of grouper fry in coastal livelihoods. In the absence of a reliable source of hatchery fry, and the preference of many farmers for wild caught fry even where hatchery fry is available, most grouper farmers rely upon wild-caught fry to stock their culture systems. Where adequate supplies of grouper fry are still available in the wild, many farmers fish for their own seed inputs which, as they are not purchased and require no cash outlay, are considered a “free” resource. This has important implications for the ability of resource poor households, with little access to financial capital, to take up grouper aquaculture.

Grouper aquaculture has been identified as an activity which can generate a relatively high return in comparison to many of activities available to coastal households (Hambrey, Tuan and Thuong, 2001). Many activities which generate a comparable return, including trading, ownership of plantations and shrimp culture are inaccessible to the majority of households due to the high levels of investment required to take up these activities. Grouper aquaculture can therefore be an important addition to household livelihoods, providing a means of savings to supplement the daily income generated by regular fishing activities (Sheriff, 2004).

As a solution to the problem of destructive fishing, aquaculture may not present the ideal alternative to fishing, as is frequently suggested. There is an assumption that aquaculture is an activity that is easily interchangeable with fishing as a livelihood activity, and that fishers are willing and able to give up fishing to take up a new and markedly different occupation. Studies suggest that fishing is deeply rooted in the lives and traditions of “fishing” communities and the identity of fishers. McGoodwin (2001) reports that fishing is regarded “not merely as a means of ensuring their livelihoods, but as an intrinsically rewarding activity in its own right – as a desirable and meaningful way of spending one’s life...prompting many fishers to tenaciously adhere to the occupation and to continue fishing even after it has become economically unrewarding.” In a study conducted by Pollnac, Pomeroy and Harkes (2001) in the Philippines, Indonesia and Malaysia, it was found that, in all three countries, fishers like their occupation and only a minority would change to another occupation, with a similar income, if it were available. In the Philippines, 95 percent of fishers surveyed reported that they would

choose to become fishers again if they had to live their life over again. They also cited pleasurable aspects of the job as reasons for staying in the fishery, including the beauty of the sea and not having to work for a boss. Fishers in the three countries who would choose to leave the fishery were characterized by a higher level of education and a lower income from fishing. The results do not support the view that fishers are the poorest of the poor, as fishers cite income as one of the reasons for choosing not to change their occupation. The level of satisfaction with fishing as an occupation suggests that fishers will not necessarily change to an alternative occupation and leave the fishery (Pollnac, Pomeroy and Harkes, 2001). Furthermore, the role of fishing in households livelihoods differs markedly from the contribution made by aquaculture. Fishing provides a source of daily income which pays for the daily needs of the household. In contrast, fish culture has been identified as being of importance to the households ability to save money and thus to accumulate assets. Proposals to encourage fishers to leave the fishery by offering fish culture as an *alternative*, may therefore fail, as fish culture cannot meet the daily needs of the household. Aquaculture can, however, provide an important supplementary activity to support livelihood diversification in coastal communities, where few alternatives may exist (Sheriff, 2004).

As a contributor to rural livelihoods, particularly those of coastal fishers, grouper aquaculture can generate potentially large financial benefits. The high-value of grouper on the export market ensures that farmers are able to generate a profit even when stocks suffer heavy mortalities. High initial investment cost is frequently cited as the principal constraint to the uptake of grouper aquaculture. Approximate investment costs for a small-scale farm are in the region of US\$1 470 in the Philippines and US\$1 010 in Indonesia (Pomeroy, Parks and Balboa, 2006), US\$516 in Viet Nam (Hambrey, Tuan and Thuong, 2001) and US\$237 in Thailand (Sheriff, 2004). Financial analyses of grouper aquaculture have indicated that grouper rearing is financially feasible, although Pomeroy, Parks and Balboa (2006) found that the capital requirements of some aquaculture systems in the Philippines and Indonesia may be beyond the financial means of many small producers, specifically broodstock and nursery/hatchery systems (Table 18). However, capital costs for grow-out are substantially lower than the broodstock or nursery systems, and are within the financial means of many small producers (Pomeroy, Parks and Balboa, 2006) (Table 19). This figure excludes holding tanks, and therefore more accurately reflects reality. Fish are most frequently kept in holding tanks of a local fish trader within the community, and therefore represent a cost which will not often be incurred at the farm level. The total production costs per market size fish from grow-out, US\$3.01 in the Philippines and US\$3.18 in Indonesia for a 600 g fish, were found to be well below the average selling price at the time of the Pomeroy, Parks and Balboa (2006) study, which was US\$6 in 2002. With the sale of market size fish able to generate this level of profit, it is not surprising to find that the annual enterprise budget show in Table 20 suggests that the cost of investment can be recouped relatively quickly. Pomeroy, Parks and Balboa (2006) conclude from their analysis that loans or other incentives to cover start-up costs could be repaid within the first or second year of production.

Despite these apparently high costs studies have shown that, with appropriate support, even the poorest can benefit from grouper culture, with implications for both household well-being and community development. For example, one study in Thailand found that grouper culture was taken up by households from all wealth groups within a community in Satun province (Sheriff *et al.*, in press). Support from the Thai Department of Fisheries in the form of materials for cage construction and seabass seed allowed households to establish a small farm of two cages with which to initiate grouper culture. Grouper fry were supplied in small quantities from the farmers fish catch, and a share of the profits returned to a centralized revolving fund for the benefit of all households in the community.

TABLE 18
Total projected capital investment costs for grouper hatchery/nursery and broodstock operations, modelled for Indonesia and Philippines (in US\$)

	Nursery/hatchery operations			Broodstock system	
	Philippines	Indonesia (small size operation)	Indonesia (medium size operation)	Philippines	Indonesia
Broodstock costs					
Male specimens				400	660
Female specimens				600	1 320
Sub-total				1 000	1 980
Land operations					
Land	6 500	728	4 850	6 500	4 850
Perimeter fencing	50	20	50	50	50
Tanks and reservoirs	11 900	1 110	8 760	6 100	3 080
Roofing, framing and siding	3 800	230	1 835	2 400	1 000
Building/structures	5 800	250	1 850	0	650
Plumbing	4 000	210	2 000	2 000	1 000
Electrical	3 500	135	1 700	2 000	1 000
Air blower	1 980	100	600	1 320	250
Sea- and freshwater pumps	2 600	315	1 800	1 700	900
Generator	2 000	0	450	2 000	450
Truck	0	0	14 000	0	0
Miscellaneous	1 000	160	900	200	150
Sub-total				24 270	13 380
Total capital investment	43 130	3 258	38 795	25 270	15 360

Source: Adapted from Pomeroy, Parks and Balboa, 2006.

TABLE 19
Total projected capital investment costs for grow-out of grouper modelled for Indonesia and Philippines (in US\$)

	Indonesia (<i>Cromileptes altivelis</i>)	Philippines (<i>Epinephalus coioides</i> and <i>E. malabaricus</i>)
Marine Operations		
Floating net cages	1 280	825
Boat	80	60
Water quality test equipment	70	80
Harvest equipment	40	45
Sub-total	1 470	1 010

Source: Adapted from Pomeroy, Parks and Balboa, 2006.

TABLE 20
Summary of annual enterprise budgets over a single production cycle across grouper scenarios modelled for the Philippines (*Epinephalus* spp.; 12 month grow-out period) and Indonesia (*Cromileptes altivelis*; 18 month grow-out period)

	Philippines			Indonesia			
	Broodstock	Hatchery / nursery	Grow-out	Broodstock	Hatchery / nursery (medium)	Hatchery / nursery (small)	Grow-out
Variable costs ¹	13 128	15 895	4 786	8 160	24 325	3 435	8 363
Fixed costs ²	4 053	7 713	2 299	2 662	8 235	668	2 108
Total expenses	17 181	23 608	7 085	10 822	32 710	4 103	10 471
Total income	23 503	45 045	14 400	83 784	106 270	12 505	20 250
Balance	6 322	21 347	7 315	72 902	73 560	8 402	9 779

Source: Adapted from Pomeroy, Parks and Balboa, 2006.

¹ Eggs, fingerlings, feed, vitamins/medication, chemicals, electricity, labour and consultants, fuel and oil, marketing/packing/harvesting, supplies, repairs.

² Depreciation of fixed assets, interest payments.

The absence of large-scale production of grouper fry has ensured that production is kept primarily in the hands of small-scale, individual family owned operations (Hambrey *et al.*, 2001; Sadovy, 2000; Sheriff, 2004), however some systems involve a large number

of cages and off-shore systems are being tested in countries including Malaysia and Viet Nam (Kongkeo and Philipps, 2001). On-going research efforts are focusing on the hatchery production of the most vulnerable and commercially important grouper species in an attempt to reduce pressure on wild stocks. Yet there may be significant socio-economic impacts if hatchery production becomes commercially viable on a large-scale, and may threaten the livelihoods of both fry fishers and small scale grouper farmers. Taiwan Province of China is one of few countries to have a successful hatchery industry and may provide some insight into the potential impacts of hatchery produced grouper, where production has led to a marked effect on demand for grouper fry and a subsequent decline in seed prices. A reduction in the value of grouper is anticipated by exporters and importers as a result of increased production (Sadovy, 2001a). However, small-scale hatchery production of grouper has been found to be a viable livelihood option providing employment opportunities and rural livelihood diversification (Siar, Johnston and Sim, 2002). In Bali, where many such hatcheries have been established, milkfish fry production has provided the basis for diversification into grouper fry, and therefore provides a particularly relevant model for transfer to countries like the Philippines. However, uncertainties remain as to the acceptability of hatchery produced grouper fry to grouper farmers and the likely livelihood impact of hatchery production on fry fishers and the value of cultured grouper.

Gender roles in the grouper fry fishery and aquaculture

The specific role of women within the grouper fry capture fishery and trade network is little understood. Within the fisheries sector, women often play an important role in post-harvest activities, which are absent from the live fish trade. However, women frequently take responsibility for trade and financial matters, and in countries such as Thailand, it is not unusual to find that the main fish and fry trader within the community is female, although fish trading beyond the community is more frequently the domain of men (Sheriff, personal communication). Grouper culture can provide perhaps the most significant opportunities for women, who are often responsible for maintaining aquaculture operations on a daily basis (Haylor *et al.*, 2003). The requirement for trash fish is high in grouper culture, and the preparation of trash fish for feeding is frequently done by women (Sheriff, 2004). Experience in Indonesia has shown that women may also find employment in the small-scale hatchery industry, providing labour as temporary workers for the counting and packaging of milkfish fry (earning in the region of US\$0.33 per 5 000 fry counted), or as brokers in the fry marketing chain (Siar, Johnston and Sim, 2002). Similar work in a grouper hatchery grading grouper fry may earn women US\$6.66 per day. The work is however, extremely hard, according to one hatchery owner (Siar, Johnston and Sim, 2002).

MANAGING CAPTURE-BASED AQUACULTURE OF GROUPER

The management of capture-based farmed groupers is complicated by several problems, including shortage of capture-based seed, disease transfer resulting from international trade in seed, high mortality rates in capture and culture, overfishing of grouper adults, etc. (Ottolenghi *et al.*, 2004). Groupers are top predators, sedentary in character and strongly territorial, typically long-lived and slow growing and many assemble in large numbers to spawn. These characteristics contribute to the ease with which over-exploitation may occur, and is engendered by the Live Reef Fish Trade (LRFT). This has already led to calls to include many of the target species in Appendix II or III of the Convention on International Trade in Endangered Species (CITES) (Lau and Parry-Jones, 1999). The Nature Conservancy (TNC) has developed a regional strategy in the Asia-Pacific that focuses on developing and applying regional models to sustainable fisheries. Many different approaches have been taken to reduce exploitation, e.g. the Bahamian government has recently approved the establishment of five no-take marine

reserves. All of these sites contain known Nassau grouper (*Epinephelus striatus*) spawning aggregations. Although stocks of Nassau grouper in the Bahamas appear to be healthy, these closures (coupled with other research activities) are being implemented to ensure that conservative management measures are taken, as a precaution against stock collapses such as those that have occurred in other locations that once held stocks of this species (Johannes, 2000). In Micronesia, Palau was among the first nations in the world to protect their grouper spawning aggregations, enforcing a seasonal closure on the Ngerumekaol (Ulong Channel) aggregation site in 1976, then creating permanent no-take marine reserves at Ngerumekaol and Ebiil (another aggregation site) in 1999. Pohnpei State in the Federated States of Micronesia has also declared permanent no-take zones around its grouper spawning aggregations (Rhodes and Tupper, 2007). Both Palau and Pohnpei have closed their grouper fisheries during the reproductive season and have limited or banned export of groupers and other species involved in the live reef fish trade.

Other regulations should be developed to control the harvest of grouper seed. The availability of capture-based grouper seed is often insufficient and unreliable (both in quality and quantity) to meet demand; low production in farming is mainly attributed to lack of seed supply (Chao and Chou, 1999; Yashiro, Vatanakul and Panichsuke, 2002; Agbayani, 2002). Disease problems due to the high transfer stress can cause high mortality rates in capture and culture. Sadovy (2000) has compiled information on the status of regulations on grouper seed capture and exports that concern capture-based aquaculture (Table 21).

A survey of CBA in Southeast Asia found that while the quantity of seed caught was significant, the production level was very low (Sadovy, 2000). The major causes contributing to this massive mortality are destructive fishing practices and gears, poor post-harvest handling, poor farming practices and conditions, and a generalized lack of experience or knowledge. This review indicated that there is a substantial fishery, and demand, for fish in the 5–10 cm range, but that the removal of this seed could have serious consequences for the future of both adult stocks and the contribution of these adults to the future of the seed fishery itself. Given the likelihood that there will be a significant increase in natural mortality for the smallest settling fish, several researchers have already proposed that fisheries for very early post-settlement (or even pre-settlement) seed is a way of gaining benefit from a resource that does not affect its long-term sustainability.

It is necessary to consider further initiatives to attain a more sustainable use of grouper stocks and greater socio-economic benefits from grouper capture-based aquaculture. One possible approach for grouper management is, as Sadovy (2000) suggests, the establishment of nursery areas where the capture fishery and culture operations occur. Another possibility is to protect key seed settlement areas and nursery habitats, such as mangrove areas, coral rubble and sea-grass environments in river mouths and estuaries, and to ensure seed production by safeguarding spawning adults. Marine protected areas (MPAs) should incorporate key settlement and nursery areas, but to date, there are few (if any) MPAs protecting grouper nursery habitat (Tupper, 2007).

Positive steps to address many of these issues are being taken by the Network of Aquaculture Centres in Asia and the Pacific (NACA) and its partners, the Asia-Pacific Economic Cooperation (APEC), the South-East Asian Fisheries Development Center (SEAFDEC), the Australian Centre for International Agricultural Research (ACIAR), and the WorldFish Center (formerly known as ICLARM), etc. In 1998 the Asia-Pacific Grouper Network (APGN) was established; this organization addresses aquaculture development, in order to:

- reduce the current reliance on capture-based “seed” for aquaculture, as the capture of wild juveniles is sometimes carried out using destructive fishing techniques that can have significant impact on the long-term status of the stock;

TABLE 21
Southeast Asia national regulations

Locality	Regulation
China	Limits the number of grouper "seed" fishers and the quantities of grouper "seed" captured A licence is needed for transporting marine "seeds" and their export is prohibited There is a management regulation of Guangdong Province for the cultivation of aquatic products in the shallow sea intertidal zone, which applies to those engaged in marine cultivation
China Hong Kong SAR	Culturists must be licensed and operate in one of 26 gazetted culture zones There are no regulations that apply to the capture of grouper "seeds" or their import or export
Indonesia	There is no management of seed resources
Malaysia	Federal legislation prohibits the use of cyanide for fishing In East Malaysia there are no special regulations for grouper seed capture. Some regulations may act indirectly, for example some gears that are made of trawl net are subject to trawl mesh size control. Grouper seeds cannot be imported for culture In West Malaysia the fishing of "seeds" is not allowed during November and December; it is only permitted during the peak season from January to April. No export of seeds smaller than 15 cm is permitted
Philippines	It is illegal to use cyanide or any other poisonous substance for fishing The scissor net is illegal Fyke net have been banned The Fisheries Code of 1998 (Republic Act 8550) prohibits the export of "seed" of milkfish and prawn but its application to grouper is not clear. This Code regulates gear/structures and operational zones for fish capture and culture Transportation and export of fish and fisheries products requires permits from the Quarantine section, including a health certificate from the Fish Health section of Bureau of Fisheries and Aquatic Resources (BFAR)
Taiwan PC	In Penghu Island, fishers are not permitted to catch any grouper seed of <6 cm The use of cyanide for fishing is illegal
Thailand	The use of push nets and fyke nets is limited. Push nets and trawlers should not be used within 3 km of the shore and the mesh size of trawlers should be ≥ 2.5 cm.
Viet Nam	Government regulations prohibit export of groupers <500 g (ex Ministry of Fisheries) There is no limit on export volumes. For export a health certificate from a provincial office, Fisheries Resources and Environment Conservation Sub-Department is needed, and requirements of the importing country satisfied

Source: Sadovy, 2000, as reprinted in Ottolenghi *et al.*, 2004.

- provide an alternative source of income/employment for coastal populations currently engaging in destructive fishing practices;
- protect endangered reef fish from the pressures of illegal fishing practices, through the development of sustainable aquaculture; and
- develop new aquaculture livelihood options and investments that will generate economic benefits for a diversity of stakeholders and employees.

Since 1996, all the above mentioned organizations have conducted workshops, with the aim of establishing a regional mechanism for research cooperation that supports the sustainable development of capture-based aquaculture in the Asian region. Emphasis has been placed on technology transfer and management strategies for the benefit of farmers and coastal populations (Ottolenghi *et al.*, 2004).

CONCLUSIONS

As a contributor to rural livelihoods, particularly those of coastal fishers, grouper aquaculture can generate potentially large financial benefits. The high-value of grouper on the export market ensures that farmers are able to generate a profit even when stocks suffer heavy mortalities. Despite high initial investment costs, studies have shown that with appropriate support, even the poorest can benefit from grouper culture, with implications for both household well-being and community development. However, based on the information reviewed in this report, capture-based aquaculture may

not be the best means to ensure a steady and sustainable supply of grouper for either the live or “non-live” fish trades. This is due to a number of problems including low availability of seed, destructive and wasteful seed collection techniques, removal of large numbers of early life history stages with subsequent impacts on adult populations and conflicts with capture fisheries, and pollution and disease resulting from culture operations.

The obvious solution to some of the problems of CBA is to develop closed-cycle hatchery rearing for all grouper species. Important advances in full-cycle culture have been made for several species, particularly in Taiwan Province of China, and full-cycle culture appears financially feasible given a large enough capital investment. However, given the financial means of most grouper culturists, and the difficulty in rearing most grouper species, it remains unlikely that many of these species will be hatchery-reared in the near future. It is also likely that hatchery production would undermine the potential contribution of grouper culture in the livelihoods of the poor. Production would most likely be taken out of the hands of small-scale producers. An increase in production if hatchery fry is available would also lead to increased supply and a likely drop in value, and lower profits. The market value of grouper is driven by its relative rarity. On the other hand, poorer farmers would probably continue to fish for grouper fry as they cannot afford to buy fry, and wild capture makes grouper culture less risky and more accessible. In the meantime, steps must be taken to improve the management of both CBA and capture fisheries for grouper. Some countries, such as Palau, have taken strong measures to protect their reef fish populations, including the closure of spawning seasons and spawning aggregation sites, bans on the export of grouper and other vulnerable species, and even complete moratoria on fishing for species in an obvious state of decline (e.g. humphead wrasse, *Cheilinus undulates*, and bumphead parrotfish, *Bolbometopon muricatum*). This has effectively stopped the live reef fish trade in Palau. In addition, the government of Palau, in cooperation with the governments of the US and Japan, has developed viable full-cycle culture for at least one commercially important grouper (*Epinephelus fuscoguttatus*), and experimentation continues with other species.

Similar to export bans on adult grouper fisheries, Sadovy (2001b) suggested that all export of grouper seed should be banned and that grouper should be cultured to market size within their own country. This would allow for more stringent management of grouper CBA, while reducing the transmission of disease via exported seed. Reduction or elimination of the more wasteful and destructive seed collection techniques (e.g. fyke nets and scissor nets) is another appropriate step. Lastly, both CBA and capture fisheries should promote the application of the precautionary principle and adopt the FAO international Code of Conduct for Responsible Fisheries (CCRF).

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Capture-based aquaculture of mud crabs (*Scylla* spp.)

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SUMMARY

There is limited understanding of wild mud crab resources and how best to manage them in many countries, particularly where fisheries management resources and enforcement capabilities are limited. The growth of mud crab aquaculture is likely to lead to changes to the ecological, socioeconomic and livelihoods currently associated with mud crab fisheries. This paper provides an overview of the issues, needs, opportunities and risks in trying to maintain sustainable mud crab fisheries, whilst supporting the ecologically sustainable development of mud crab aquaculture.

The uncontrolled fishing of juvenile crabs for farming in some countries has led to recruitment overfishing, even though mud crabs are very fecund and have extended spawning seasons over much of their range. Conserving of mud crabs primary habitat, mangrove forests, is critical to supporting their populations, as is the regular monitoring of stocks to guard against their over-fishing. Environmentally sustainable farming of mud crabs in mangrove pens is seen as an important tool in both conserving mangrove forests, and expanding farm production areas.

Significant growth of mud crab aquaculture is only going to occur from hatchery sourced seed-stock, as wild populations are at either at their limit or over-fished in many countries. Such growth will also be dependent on the development of formulated diets to reduce mud crab farming's current dependence on trash-fish, a resource which is already under pressure from other types of aquaculture.

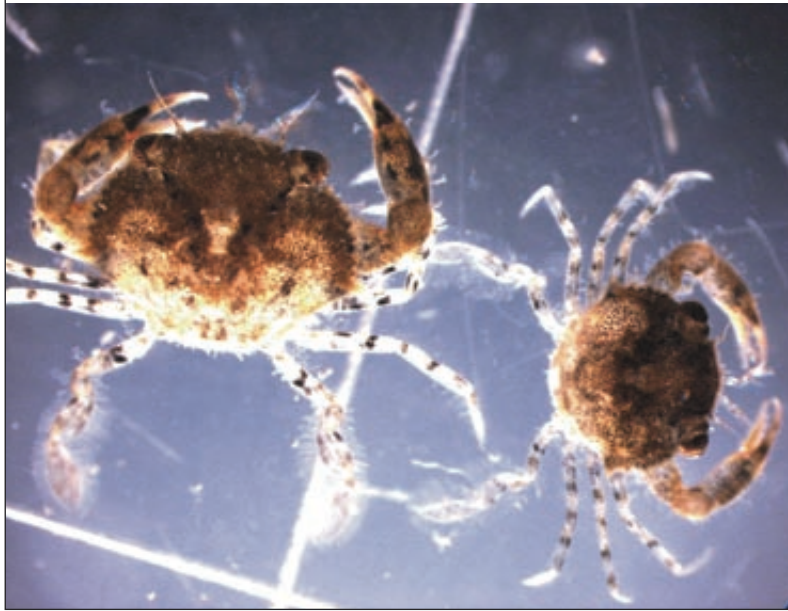
During the transition from an industry dependent on wild mud crab seed-stock and wild feed resources, to hatchery produced seed-stock and formulated feeds there will be changes to the current supply chains, and employment opportunities. Consideration needs to be given to programmes to assist fishers of both wild mud crab seed-stock and trash-fish (and associated middlemen) as the farming of mud crabs moves to a more industrial scale as is currently taking place in China, as both groups are amongst the poorest in many coastal communities.

DESCRIPTION OF MUD CRABS AND THEIR USE IN AQUACULTURE

Species

There are four species of mud (or mangrove) crabs in the genus *Scylla*, *S. serrata*, *S. olivacea*, *S. tranquebarica* and *S. paramamosain* (Keenan, 1999b; Keenan, Davie

FIGURE 1
Juvenile mud crab



COURTESY OF D. MANN

and Mann, 1998), all of which support capture fisheries and aquaculture. In most countries where mud crabs are fished or farmed, they are an important source of income from both export and local sales, and are utilized by recreational fishers.

Life cycle

All mud crabs commonly display 6 larval stages; 5 zoeal stages, followed by a megalops larval stage which precedes the first crab stage (Figure 1). Mud crabs typically undergo 14–16 moults prior to reaching their maximum size. Reported daily weight gain for mud crabs varies from 1–4 g per day and varies with

species, and sex, with males reportedly growing faster than females (Trino, Millamena and Keenan, 1999b; Christensen, Macintosh and Phuong, 2004). All mud crabs can mature within their first year of life, with *S. paramamosain* maturing at a size of 102 mm carapace width at around 160 days from settlement (Le Vay, Ut and Walton, 2006; Le Vay, Ut and Walton, 2007), whilst *S. serrata* have reportedly grown to 750 g within 145 days and shown signs of maturity at day 147 (Field, 2006). They are highly fecund with individual females carrying over 3 million eggs. Apart from spawning migrations where females may travel considerable distances offshore most crabs appear to move little within their local habitat, which is typically mangrove forest (Hill, 1975; Hill, 1976; Le Vay, Ut and Walton, 2006; Le Vay, Ut and Walton, 2007). Mud crabs of different sizes occupy different niches within mangrove forests and the adjacent sub-tidal zone (Walton *et al.*, 2006).

Habitat

Mud crabs are a common component of the fauna of mangrove forests, usually burrowing in mud or sandy-muds. They have a diverse diet and are omnivorous in nature, feeding on a wide range of animal and plant resources (Hill, 1976).

Geographical distribution

The distribution of mud crabs extends from South Africa, along the southern coasts of middle-eastern countries, across the Indian Ocean and northerly to the southern tip of Japan, east as far as Micronesia and south to the east coast of Australia. *Scylla serrata* is the most widely distributed species, whilst Indonesia appears to be the centre of diversity for the genus, where all four species of *Scylla* are found.

Capture fishery

The mud crab is a targeted species for harvest across its range. Techniques vary from catching by hand to the use of fishing gear including tangle nets, baited traps and lift nets. Fishery trends for the last decade are detailed in Table 1. However it should be noted that figures for Sri Lanka and Australia were missing from the FAO database and not included here, so that these figures represent an underestimate of the production of

TABLE 1
Capture of *Scylla serrata* in tonnes

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Indonesia	7 980	7 342	8 298	8 161	8 707	8 774	11 753	11 240	14 802	20 129	18 750
Philippines	4 835	4 258	1 133	1 124	1 211	1 247	1 604	1 692	1 663	1 466	1 432
Taiwan PC	1 339	935	180	215	269	299	230	337	375	9	717
Thailand	5 776	4 243	4 031	3 732	5 736	6 921	5 417	3 823	1 259	2 859	1 865
Fiji Islands	234	208	290	270	281	250	268	180	82	324	280

Source: FAO-FIGIS

Scylla serrata. Whilst Indonesia has shown an increasing catch, all other major producers have shown either a decreasing or static catch.

Harvest products

Juvenile crabs or crablets are actively harvested throughout Southeast Asia for use as seed-stock for crab farms. Sizes harvested vary from a few centimetres across the carapace to just under harvest size for sale direct to market.

Crabs of close to, or at a marketable size are caught for a range of activities. Crabs which have recently moulted and have not fully grown to fill their new shells are commonly referred to as “empty” crabs. Such crabs may be put into fattening pens, ponds or enclosures and fed until they are “full” and ready for market.

Other crabs of varying sizes will be caught and put into soft shell shedding facilities. Such crabs are commonly placed in individual containers and monitored until they moult. On moulting the crabs will either be chilled and put on ice, or frozen for the soft shell crab market, where all parts of the crab can be consumed as the shell has not been allowed to harden after moulting. Finally, hard-shell crabs of a marketable size are collected, secured to ensure traders and customers are not injured by their powerful claws and sold; most commonly in the live form (Figure 2). The size of crabs marketed varies with species. In the Philippines *S. serrata* is most commonly harvested at weights over 500 g, whilst for *S. olivacea* and *S. tranquebarica* the weight is usually over 350 g.

Whilst mud crabs are usually a targeted species, they may be caught occasionally in various nets which are targeting other mangrove or reef species and are caught as they move across their habitat. Only a very small part of the mud crab harvested is bycatch of other fisheries. Mud crabs adapt very well to a farmed environment. With their omnivorous diet they will eat a wide range of feeds, from trash fish through to pelletised aquaculture feeds.

There are a number of problems encountered by collectors and farmers, involved with using wild harvested crabs in various farming systems. Stock will often consist of a wide variety of sizes, and as mud crabs have a tendency to cannibalism, larger specimens will often predate on smaller crabs, causing significant mortalities amongst farm stock.

FIGURE 2
Live crabs on sale in Viet Nam



COURTESY OF C. SHELLEY

Life cycle status

Mud crabs born in captivity have been successfully mated with both wild and other captive stock so that some organizations and companies now use domesticated stock. Almost all hard shell, mature females collected from the wild will have been impregnated and will spawn if held under appropriate conditions. Each mature female will usually be able to spawn 2 or 3 batches of larvae when held under satisfactory conditions following a single copulation.

The use of farm produced seed is now becoming common in Viet Nam and China in particular. In some countries, such as the Philippines, there has been caution in the use of hatchery produced stock to date (Shelley, 2004a). Farmers have reported a range of concerns with crablets produced in hatcheries; will they be as robust as wild stock, will they grow as fast, will they be more prone to disease, and which is the better value for money – wild or farm produced stock?

In some countries where mud crab fisheries are actively managed e.g. Australia, crablets or under-size crabs cannot be legally harvested.

Farming techniques

Considerable efforts have been made over the last few decades to develop effective technology for mud crab aquaculture (Brick, 1974; Angell, 1992; Heasman and Fielder, 1983; Keenan and Blackshaw, 1999a; Anon., 2001; Anon., 2005; Shelley *et al.*, In Press; Wang *et al.*, 2005). A significant body of work on mud crab aquaculture is contained in a number of workshops, conference proceedings and review papers (Angell, 1992; Anon., 2001, 2005; Keenan and Blackshaw, 1999a). The successful development of techniques to support the mass culture of mud crab larvae in hatcheries drove the rapid expansion of mud crab farming in China during the 1990s, and its subsequent expansion, often in polyculture with shrimp, fish and algae (Wang *et al.*, 2005). In China, in 2003, over 34 000 ha of culture area for mud crab produced just over 100 000 tonnes whilst over 79 000 tonnes were taken from the wild, making China the worlds largest producer of mud crabs (N. Zhou, Network of Aquaculture Centres in Asia-Pacific, personal communication).

Until recently, larval production of mud crabs had been difficult with low and inconsistent quantities of crablets produced. However in recent years average survival rates have increased (Wang *et al.*, 2005), and production of crablets for farms is now practised at a commercial scale in countries including Viet Nam, China, Philippines and Australia. Maintaining stable water quality conditions, minimising bacteria build-up and providing high quality feeds at appropriate densities have proven to be the key needs for successful larval production of mud crabs (Shelley *et al.*, In Press).

There are a range of nursery systems used to grow mud crabs from the late zoal stages, through megalops to settlement and metamorphosis to crablet. A variety of tanks, ponds and *hapa* nets within ponds have been successfully used. A complex 3-dimensional habitat within such systems increases the densities which can be carried by any particular system. Suitable habitats include netting, plastic mesh and artificial sea grass. An appropriate temperature and salinity range is required in nursery systems to maximize survival (Ruscoe, Shelley and Williams, 2004).

The grow-out of crabs is undertaken in various systems. The two major system types are: a) open; which includes ponds and mangrove enclosures where crabs are maintained at varying densities, and b) closed; where crabs are held in individual containers e.g. soft shell crab (Figures 3 and 4), or restrained in some way e.g. fattening enclosures (Figure 5). In Viet Nam culture techniques have been defined as extensive, intensive and cage culture (Thach, 2003). Crabs were fed on diets including trash fish, molluscs and small crustaceans. In extensive system seed crabs were stocked at 1 crab/5–10 m² with wild seed, 1 crab/2–5 m² for smaller hatchery seed, whilst an intensive stocking rate was considered to be 1–1.5 crabs/m². Cage culture in Viet Nam is a fattening exercise where

large crabs (200–400 g) are held in high densities of 35 crabs/m² and fed until marketable. Lindner (2005) further described systems in Viet Nam, that included a range of low-input systems such as pens in mangrove forests and extensive shallow mangrove silviculture ponds that do not require supplemental feeding. In some areas in Viet Nam rice fields are flooded with brackish water that contains crab and/or shrimp seed, which become an important technique for farmers to supplement their income. More intensive Vietnamese systems that stock ponds at higher densities using purchased crablets commonly use trash fish or shellfish as feed and can produce 1–2.0 tonnes/ha⁻¹/crop (Lindner, 2005).

In open production systems the cannibalistic behaviour of mud crabs is a major impediment to their high density production. Cannibalism can be minimized by using relatively low stocking densities and by utilizing some form of enclosures or shelter to provide refuge. Antagonistic behaviour between crabs can also result in loss of limbs by mud crabs. As a result, a percentage of crabs at harvest will have limbs missing and will fetch a lower price, or need to be kept longer on the farm for limbs to regenerate. To minimize the impact of cannibalism on survival a useful management strategy is to routinely undertake partial harvests of crabs (Say and Ikhwanuddin, 1999) of a commercial size in grow-out systems, leaving sub-harvest size crabs to grow to harvest size with a reduced incidence of predation, in more space and with less competition for feed (Christensen, Macintosh and Phuong, 2004).

The statistics for aquaculture production of the mud crab (*S. serrata*) in Tables 2 and 3 indicate that in recent years Chinese production of mud crabs is approximately an order of magnitude greater than that of the next highest producing country

FIGURE 3
Mud crab fattening bamboo box in the Philippines



COURTESY OF C. HELLEY

FIGURE 4
Mud crab individual fattening bamboo boxes in the Philippines



COURTESY OF D. MAMN

FIGURE 5
Mud crab fattening pen in Indonesia



COURTESY OF C. KEENANA

(Viet Nam). In the last few years the Vietnamese production of farmed mud crabs has increased significantly, however statistics were not available from FAO for the country. It should also be noted that FAO statistics are nominally for *S. serrata*, however as three other species of mud crab are farmed in different countries it is believed that these figures are likely to more accurately represent production of the genus *Scylla*, rather than the species (*S. serrata*). These figures also demonstrate that the aquaculture production of mud crabs now exceeds that of wild harvest, notably because of the massive growth in the farming of mud crabs in China in recent years.

TABLE 2
Aquaculture of *Scylla serrata* in tonnes

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
China	0	0	0	0	0	0	0	0	100 870	108 503	111 423
Indonesia	1 906	1 339	5 176	866	5 143	5 126	3 879	9 039	7 152	2 243	4 379
Malaysia	623	381	277	231	188	225	219	311	204	174	162
Philippines	2 782	2 463	3 759	4 033	4 826	4 968	4 608	4 747	4 809	6 245	6 861
Taiwan PC	1 526	797	430	796	381	315	423	239	226	239	240
Thailand	45	132	115	19	9	9	5	10	10	23	20

Source: FAO-FIGIS

TABLE 3
Aquaculture value of *Scylla serrata* in US\$

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
China	0	0	0	0	0	0	0	0	201 740	216 959	245 329
Indonesia	3 240	2 343	8 282	1 559	9 257	9 227	6 982	4 831	2 014	3 948	9 108
Malaysia	1 389	1 673	1 184	1 262	601	743	971	886	795	679	463
Philippines	18 031	14 375	22 430	16 968	23 782	21 270	16 713	19 642	19 374	28 375	30 775
Taiwan PC	15 530	8 538	4 464	8 274	4 157	3 235	4 090	1 880	2 109	2 159	1 907
Thailand	91	394	308	43	28	27	19	40	41	92	85

Source: FAO-FIGIS

DESCRIPTION OF MUD CRAB FISHING

Gear used to fish for juveniles

The techniques for collection of juvenile crabs were comprehensively reviewed in the seminar on mud crab trade and culture, conducted by the Bay of Bengal Programme (Angell, 1992). In particular details were provided for the Bay of Bengal (Sivasubramaniam and Angell, 1992), and countries attending the seminar (Cholik and Hanafi, 1992; Kathirvel and Srinivasagam, 1992; Khan and Alam, 1992; Ladra, 1992; Tookwinas, Srichantulk and Kanchannavasiste, 1992). For juvenile and larger crabs, the gear used can include baited traps, lift nets or lines, together with hand held hooks, scoop nets, gillnets and fish corrals. For crab larvae and very small juvenile crabs, which are yet to settle, fine meshed push nets or drag nets can be used.

In the Philippines a small meshed net is mounted on a V-shaped bamboo frame and pushed across muddy substrates to collect juveniles, whilst for larger crabs a variety of traps are used with fish baits to attract the crabs. In Viet Nam juvenile crabs are collected from canals and coastal waters using a bottom seine net (Johnston and Keenan, 1999).

Statistics on juvenile collection

Whilst production figures on farmed mud crabs are available for most countries, there appear to be no official statistics on the collection of juvenile crabs. It has been estimated that juvenile (20–60 mm carapace width) *S. paramamosain* can be found at densities of over 1 000 ha⁻¹ (Le Vay, Ut and Walton, 2007) in some locations where their commercial harvest is undertaken.

Post-harvest techniques

Juvenile crabs caught specifically for farming will typically be packed, without water, in boxes or bags and kept in a moist environment during transport, either to a middleman or farmer. Juvenile crabs can be transported in this manner successfully for several days without significant mortalities if properly packed.

If crabs of commercial harvest size are collected there are 3 main ways in which they are handled. *Method one* for hard shelled, “full” crabs is for the crabs to be tied to secure their limbs and packed into boxes or bags, kept moist and then transported to market, typically via an agent, or middleman. The vast majority of mud crabs are sold live. *Method two* is the fattening of “empty” or “soft” recently moulted mud crabs (Ladra, 1992; Liong, 1992; Rattanachote and Dangwatanakul, 1992). This can be regarded both as a post-harvest technique and as a specific type of aquaculture. In India, Patterson and Samuel (2005), described the success of a crab fattening project operated by a self-help women’s group. In the wild fishery approximately 7–10 percent of the catch on average was “empty” and would usually be discarded, but these crabs when fattened for 21–30 days to a “full” crab, increased in average value by over 200 percent (US\$4.63 to US\$9.53 per kg), making a good profit for the women's group. *Method three* is for smaller crabs in the range of 50–150 g. Such crabs can be held in individual containers and checked regularly to see if they have moulted. On moulting, whilst their shells are still soft, they are either chilled or frozen for the “soft shell” crab trade, a market segment rapidly gaining in popularity, particularly because soft shells fetch an even higher price per kilogram than do hard shell crabs.

AQUACULTURE DEPENDENCY ON THE WILD STOCK

Reliance on wild seed

As mud crab hatchery development on a commercial scale has only occurred in a few countries, farms in most countries are dependent on wild caught stocks. It is only in

countries such as China and Viet Nam, where there is significant expansion of the mud crab hatchery sector, that hatchery produced seed-stock will contribute a significant percentage of overall production in the near future. In the Philippines it is estimated that 95 percent of crab seedstock is collected from the wild. In contrast in countries where collection of wild seed stock is banned under management plans e.g. Australia, the farming of crabs is totally dependent on hatchery produced stock.

Limits of seed supply

The loss of mangrove forests, over-exploitation of wild crab stocks and inadequate wild production to support increasing demand are the key factors that have driven the development of hatchery technology for mud crabs (Lindner, 2005). The supply of seed-stock from the wild varies over time, as recruitment to the fishery is seasonal (Walton *et al.*, 2006b), as reflected in the variation of zoeal abundance in near shore waters (Sara *et al.*, 2006). As zoeal distribution and abundance is correlated with salinity, recruitment to different areas will also be affected by climatic variability (Sara *et al.*, 2006).

Heavy fishing pressure on mud crab fisheries in the Philippines has been reflected in decreasing relative abundance, mean size at capture, yield and catch per unit effort (CPUE) in two studies (Lebata *et al.*, in press).

In some municipalities in the Philippines, the number of crablets being transported out of the municipality is being restricted because of fears of over-fishing. A number of research organizations are helping municipalities by assessing their stocks of crabs and providing support to policy and management plans.

Threats to mud crabs generally, which would also impact on seed supply, can include algal blooms, industrial and urban run-off, and their over-exploitation such as occurred in India in 1990 which led to their export being banned (Aldon and Dagoon, 1997). The supply of crab seed-stock can also be limited by the number of fishers targeting the species (Say and Ikhwanuddin, 1999).

In some countries up to 4 species of mud crab can be found. As a result, stocking with wild crab seed-stock can result in multiple-species being grown in the same grow-out system. This creates problems as all species have different growth rates, and the faster growing species may well cannibalise the slower growing species, and generally complicate animal husbandry.

The need for a consistent, reliable year-round supply of mud crab seedstock to support farm expansion will underpin the future significance of mud crab hatcheries.

Economics of wild versus farmed seed

There are a number of reports on the economic performance of mud crab culture (Aldon, 1997; Baliao, De Los Santos and Franco, 1999a; Cann and Shelley, 1999; Say and Ikhwanuddin, 1999; Christensen, Macintosh and Phuong, 2004; Samonte and Agbayani, 1992a; 1992b; Trino, Millamena and Keenan, 1999a). Information regarding wild seed versus farmed seed appears anecdotal at best, with most trials using either wild or farmed seed, not both. As hatchery reared stock have only relatively recently become available in a few countries, most economic reports to date were based on grow-out of juvenile crabs collected from the wild (Figure 6).

It has been demonstrated that profitable crab farming operations can occur using wild seed-stock at various densities (Trino, Millamena and Keenan, 1999a), although the most profitable density is likely to be related to both the system and management of operations that can minimize cannibalism and improve the food conversion ratio (FCR). It has also been shown that farming mono-sex cultures of crabs may increase economic return, with one report reporting a return on investment of over 100 percent (Trino, Millamena and Keenan, 1999a).

The effects of harvesting regime on the profitability of mud crab farming in ponds was examined by Rodriguez, Trino and Minagawa (2003) who found that a bimonthly

FIGURE 6
Hatchery-produced mud crab juveniles



COURTESY OF D. MAMU

selective harvesting regime could improve profits compared to one terminal harvest. They argued that a selective harvesting regime increased overall survival to harvest as more space was available to those crabs left in the ponds and a more homogenous size range of crabs was maintained, as typically large crabs enter harvesting traps first.

The profitability of growing mud crabs in mangrove pens has also been documented (Trino and Rodriguez, 2001). They found a stocking density of 1.5 crabs/m² fed on a mixed diet of mussel flesh and fish bycatch to be most profitable, obtaining returns of 49–68 percent return on capital investment.

Dependence on wild caught feed

In a workshop examining the status of mud crab aquaculture, Allan and Fielder (2003b) summarized that “... diet development to reduce dependence on trash fish in Indonesia, the Philippines and Viet Nam, and to allow for grow-out in Australia, was the highest overall priority for mud crab aquaculture.” This reflects the current situation in most countries where mud crabs are farmed, where the principal source of feed is wild caught trash fish and molluscs.

A key challenge facing the rapidly growing mud crab farming sector in countries such as Viet Nam, Indonesia and the Philippines is the lack of a formulated aquaculture feed made especially for mud crabs (Allan and Fielder, 2003a). There are concerns that industry growth may ultimately be constrained by the dependence on low value trash fish and fishmeal popularly referred to as the “fishmeal trap” (Funge-Smith, Lindebo and Staples, 2005).

Whilst formulated mud crab feeds are now available in a number of countries where mud crabs are farmed e.g. China, Philippines and Viet Nam, there is scope to improve formulations and to reduce their cost.

Availability of wild feed

Wild caught feed resources

Crabs have a varied diet naturally and seem to grow well on a wide variety of feeds. In the Philippines typically chopped trash fish are used, but animal hide, entrails and snails (golden kuhol) have also been reported (Aldon, 1997), as has brown mussel flesh (Rodriguez, Trino and Minagawa, 2003). While research is underway to develop a specialized crab feed, trash fish resources in many regions are under severe pressure. This pressure is resulting in higher prices for trash fish and also conflict with human consumers of seafood, who themselves would like to consume so-called “trash fish”.

ENVIRONMENTAL IMPACTS OF JUVENILE CRAB FISHING

Impact of the seed fishery on wild stocks

Removal of mud crab seed-stock from the wild can result in recruitment failure for the stock as a whole if fishing pressure is high enough. This appears to have happened in a range of localities in the Philippines. The impact of the seed fishery on the wild stocks will depend on the size of the population, the take of the fishery, food availability and maintenance of the habitat supporting the fishery. In Viet Nam, Lindner (2005) considered “there may be limited scope for further expansion of crab fattening due to its reliance on wild crab stocks that are claimed to be fully exploited”.

It has been shown that mud crab recruitment can be continuous throughout the year in some fisheries which may explain why such fisheries can be quite resistant to heavy fishing pressure (Le Vay, Ngoc Ut and Jones, 2001). However, unlike the fishery examined by Le Vay, Ngoc Ut and Jones (2001), few mud crab fisheries have been well researched, so that changes in baseline variation in crab abundance can be monitored to assess the effectiveness of either management provisions, habitat change or fishing pressure.

Impact of seed collection on the ecosystem

Apart from over collection of mud crab seed-stock resulting in decreased crab populations in some areas, little appears to have been researched regarding the impact on ecosystems of this practise.

SOCIAL AND ECONOMIC IMPACTS OF THE FARMING

Social impacts

Description of the supply chain

Whilst there are variations from country to country, the supply chain from the collection of a juvenile crab may include one or more middlemen to a farmer, and then from a farm a further number of middlemen to an exporter, or if for local trade to a retailer (Cholik and Hanafi, 1992). In some countries the crabs marketed locally are often those that are not of sufficient quality to be exported (Khan and Alam, 1992).

The supply chain often has an additional link in it which includes mud crab fattening. Where fishermen or farmers harvest post-moult or “empty” crabs, these may be sent to a farmer who specializes in fattening crabs (Rattanachote and Dangwatanakul, 1992).

How does aquaculture change supply chain arrangements

The major change in the supply chain occurs if hatchery operations are introduced into the industry. In time, growth of the hatchery sector for mud crabs may result in collectors of wild seed losing a source of income if farmers favour hatchery stock over wild. There are a number of reasons why hatchery produced stock would in time be favoured by farmers. Stock would be of a more uniform size (minimizing cannibalism), of just the one species and also available in large numbers on a year-round basis.

However in the short- to medium-term, the demand for mud crab seed-stock in most countries would indicate that collection of wild stock will remain a viable fishery for some time, subject of course to sustainability issues.

How does aquaculture influence employment and skill development

In Bangladesh it was reported that most crab catchers are otherwise jobless and landless (Khan and Alam, 1992). As more hatchery operations for mud crab start up there will be an increased demand for skilled and semi-skilled technicians, and for training programmes to support such development. Viet Nam has developed a very successful train-the-trainer programme in mud crab aquaculture which has supported the rapid expansion of the mud crab hatchery sector in that country (Shelley, 2004b).

With hatchery production of crab seed-stock, the expansion of the industry will not be limited by the supply of wild seed-stock in the medium to long term. As a result the industry is expected to expand dramatically over the next few years. This will stimulate a demand for more workers to manage ponds, harvest and pack crabs and in support industries such as feed production, transportation and construction.

Economic issues

Winners and losers

In the Philippines, Aldon (1997) provided advice on how to establish and operate mud crab culture in mangrove areas. Information on the economics of such a venture indicated that a return on investment of 44 percent was possible, with a payback period on establishment costs of 2.27 years. This was based on a production yield of 600/kg/h⁻¹ and survival rates of 65–70 percent. A similar model from the Philippines (Baliao, De los Santos and Franco, 1999a) had a payback period of 1.4 years.

Mud crab aquaculture is now commonly being undertaken in enclosures or pens in mangrove forests (Baliao, De los Santos and Franco 1999b; Chang Wei Say and Ikhwanuddin, 1999; Rodriguez, Trino and Minagawa, 2001; Trino and Rodriguez, 2002). This is putting a significant value on mangrove forests and encouraging their conservation and in some places re-planting. Whilst mangrove enclosures are productive systems for mud crab aquaculture, the mangroves themselves are also valuable and critical to sustain wild mud crab fisheries (Ronnback, 2001).

MANAGEMENT

Amongst all the countries where mud crabs are commercially fished, the fishery is most highly regulated is Australia. All states and territories where mud crabs are fished have detailed management plans, which are backed up by legislation and enforcement by specialised fisheries enforcement agencies. The number of commercial fishers and the number of crab pots used is strictly limited. All commercial mud crab fishers in Australia must complete logbooks recording the date, the number of crabs caught and the location of their catches. Information from these logs are collected on a monthly basis, entered into databases and analysed routinely. For recreational fishers, the number of crab pots that can be used, the number of mud crabs in possession and where and when they can fish is legislated. Considerable research and monitoring is also targeted on the mud crab fisheries in Australia to ensure management arrangements are working (Hay *et al.*, 2005). No crabs under a specified minimum size limit can be collected, so utilization of mud crab seed-stock in Australia is not an issue as none is allowed. In Queensland, all female crabs are protected, so only males can be legally harvested by commercial or recreational fishermen, making Queensland the most regulated mud crab fishery in Australia.

Many countries have regulations or plans, which seek to control mud crab fisheries. However economic necessity and the lack of resources to enforce such legislation appear to result in a low level of compliance in most countries. In many countries

strings of immature, under legal size crabs are routinely sold for human consumption, in addition to the collection of seed-stock for farming, putting enormous pressure on the reproductive population.

Whilst there have been some efforts to examine the potential for stock enhancement of mud crab fisheries from a research perspective, there appears to have been little long-term efforts to do this on a commercial scale, apart from Japan.

CONCLUSIONS

Mud crabs can be the focus of commercial fishing activities throughout their life cycle in many countries, which can put intense fishing pressure on stocks. Juveniles (crablets) of varying sizes can be collected to stock farms for grow-out for either hard or soft shell crab production, whilst larger crabs are harvested for direct sale, or for fattening if the crabs are “empty” when collected, as is the case in the first few weeks post-moult.

The development of hatchery technology for mud crabs to support industrial scale development of crab farming is beginning to impact on the ecological, socio-economic and livelihoods traditionally linked to mud crab fishing in some countries.

The growth of mud crab aquaculture will increase demands on the collection of wild stock for grow-out and for limited trash fish and molluscan resources to feed crabs. To cope with increasing pressure on mud crab fisheries innovative management regimes need to be developed where fisheries management and enforcement resources are limited. The need to develop economically viable feeds for mud crabs to minimize the use of trash fish, is one shared with many types of aquaculture, as is the replacement of fishmeal and fish oils generally in stock feed formulation.

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Oyster capture-based aquaculture in the Republic of Korea

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SUMMARY

Oysters are considered to be the most important molluscan shellfish in the aquaculture industry of the Republic of Korea, which, in 2005, produced 251 706 tonnes of oysters. In the Republic of Korea the Pacific oyster, *Crassostrea gigas*, is widely cultured along the southern coast where a number of small, shallow bays (mostly <10 m in depth) are protected by numerous islands. Oysters are intensively cultured in these bays with a longline suspended culture system. The Korean oyster industry uses mainly wild-caught oyster spat as seed. This is collected from mid-summer to early fall. Oyster spat that settle on the strings undergoes 7–9 months of hardening in intertidal areas. After the hardening period, the oysters are relocated to a grow-out field in the middle of the bay. The market-size products are harvested during late winter and mid-spring following a grow-out period lasting 9–11 months. Approximately 3 400 families are engaged in the oyster longline culture industry on the southern coast, with 22 000 full-time employees in 2005.

INTRODUCTION

The modern oyster culture technique was introduced to the Republic of Korea at the end of Nineteenth century from neighboring Japan. According to the National Federation of Fisheries Cooperatives of Korea, the first oyster culture licence was issued in 1907 and in 1918 approximately 133 tonnes of oysters were produced from 1 425 hectares. Culture techniques in the early Twentieth century were rather primitive and limited to bottom culture in intertidal areas of inner bays using rocks or wooden poles as substrates for seed collection and subsequent grow-out. In the 1960s, modern suspended culture techniques using longlines and rafts were introduced and the culture area subsequently expanded from the intertidal area to deeper waters offshore. Owing to this technical innovation, an estimated 53 327 tonnes of oysters were landed in 1963, an approximate 7 fold increase from the previous year's landings of 7 036 tonnes. In 2005, approximately 251 700 tonnes of oysters were produced from 8 042 hectares.

Table 1 lists the oyster species occurring in Korean waters. According to Min (2004), 14 species of oyster have been identified in Korean waters, although only *Crassostrea gigas* is extensively used in the oyster industry. *Ostrea denselamellosa*, a larviparous flat oyster species, has been cultured in tidal flats on the southwest

TABLE 1
Oyster species in Korean waters

Family	Species	Common name	Distribution	Remarks
Ostreidae	<i>Ostrea denselamellosa</i> Lischke 1869	Flat oyster	West and south coasts	Used in bottom culture on the south coast
	<i>Ostrea circumpicta</i> Pilsbry 1904	-	Jeju Island	-
	<i>Dendostrea folia</i> Linnaeus 1758	-	Jeju Island	-
	<i>Dendostrea crenulifera</i> Sowerby 1878	-	--	-
	<i>Crassostrea gigas</i> Thunberg 1793	Pacific oyster, Pacific cupped oyster	West, south and east coasts	Mainly cultured in small bays off the south coast using longlines and bottom culture on the west coast
	<i>Crassostrea pestigris</i> Hanley 1846	-	South coast	-
	<i>Crassostrea nipponica</i> Seki 1934	-	East coast	-
	<i>Crassostrea ariakensis</i> Fujita and Wakiya 1929	-	West and south coasts	Cultured in river-mouth area
	<i>Crassostrea nigromarginata</i> Sowerby 1871	-	Jeju Island	-
	<i>Saccostrea kegaki</i> Torigoe and Inobe 1981	-	Jeju Island	-
Gryphaeidae	<i>Neopycnodonta cochlear</i> Poli 1795	-	Jeju Island	Depth 50–300 m
	<i>Hytissa hyotis</i> Linnaeus 1758	-	Jeju Island	-
	<i>Parahytissa inermis</i> Sowerby II 1871	Kaki-tsubata	Jeju Island	-
	<i>Parahytissa chemnitzii</i> Hanley 1846	-	Jeju Island	-

Source: Min, 2004

coast using rocks and used tires as substrate. *Crassostrea ariakensis* is an estuarine species commonly occurring in low salinity environments. Due to its fast growth rate and size, e.g. achieving 100–150 mm in shell length within 2–3 years after hatching, small-scale aquaculture has been attempted using a suspended longline system off the southwest coast. Several species of oysters are also found in Jeju Island, located on the southernmost part of the Korean peninsula, although none of them are currently utilized in the oyster industry (Table 1). Although several species of oysters found in the country are potential candidates for the aquaculture industry, only the Pacific oyster (*Crassostrea gigas*) is extensively farmed. Most of the Korean oyster landings come from small bays on the south coast where *Crassostrea gigas* is cultured using the suspended longline system. In contrast, wild oysters are also harvested commercially on the west coast where they are found on rocky substrates on tidal flats (Figure 1).

ECOLOGY OF *CRASSOSTREA GIGAS*

Nomenclature

Scientific name:

Class Bivalvia

Order Ostreoida

Family Ostreidae

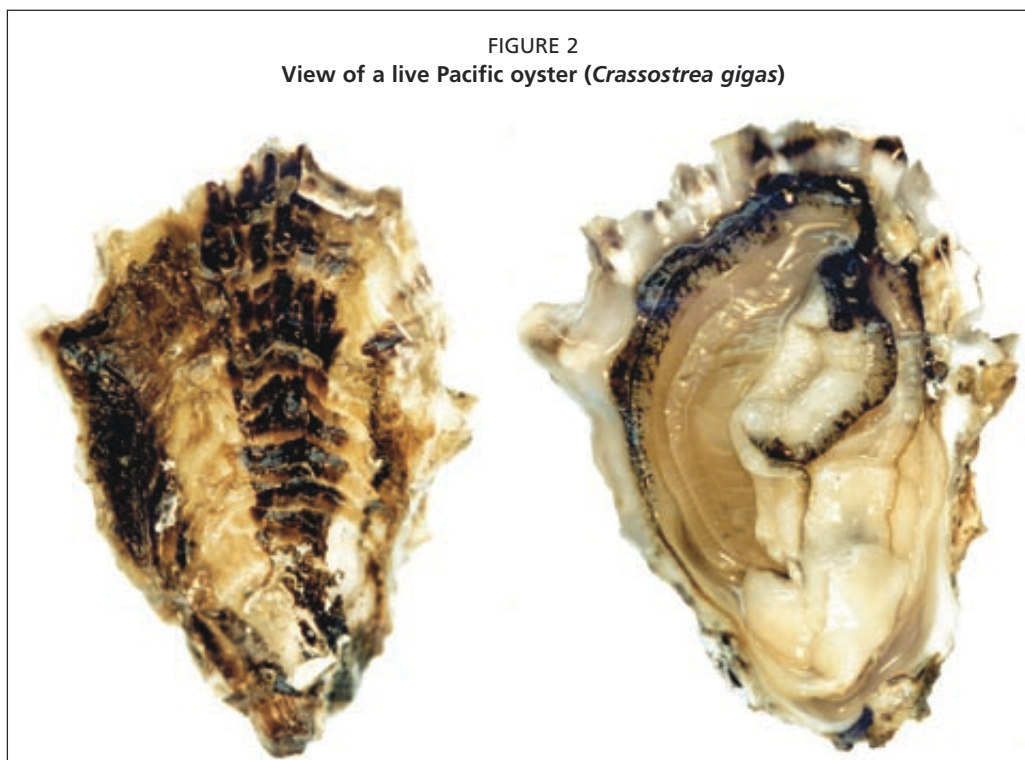
Crassostrea gigas Thunberg 1793 (Figure 2)

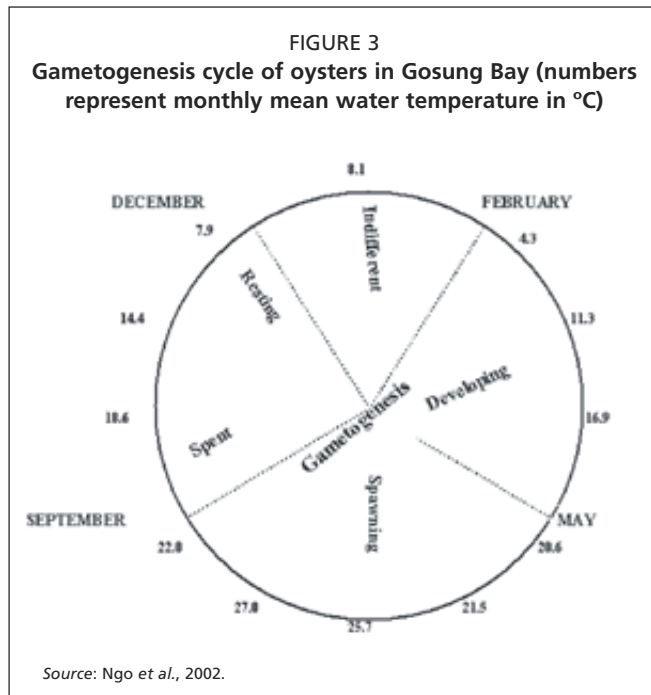
Common name:

The preferred common names are the Pacific oyster and Pacific cupped oyster. Other common names include the giant Pacific oyster and the Japanese oyster.

Distribution range in Asia

Crassostrea gigas is found in the west, south and east coast of the Korean Peninsula, Northern Bohai Bay of China to China Hong Kong Special Administrative Region (SAR), from Okinawa to Hokkaido in Japan and from Vladivostok to the Kamcharka Peninsula, Russia.





Annual gametogenesis

Ngo, Kang and Choi (2002) reported a match between seasonal changes in the surface seawater temperature and gametogenic changes in the Pacific oysters in Gosung Bay off the southeast coast of the Republic of Korea (Figure 3). *Crassostrea gigas* in the Gosung Bay commences gametogenesis in February when the water temperature reaches 4–7 °C. In late May to early June, oysters become fully mature and ready to spawn. The diameter of fully mature oocytes varies from 50–70 µm. Spawning occurs as early as mid-June and can continue until the end of September when the temperature ranges from 23–26 °C. Abrupt changes in water temperature and salinity induce spawning in oysters. Microscopy photographs of both the

ovary and testis are displayed in Figure 4.

According to Kang *et al.* (2003), oysters in Gosung Bay spawn twice a year, once in late June and again in late July to mid-August. During spawning female oysters may discharge as much as 60 percent (average 40 percent) of their body weight as eggs. The spawning intensity and quantity of egg released from single oysters is greater in the first spawning peak which is late June (Figure 5). The fecundity of the oysters in Gosung Bay varies from a few million to 200 million eggs during the spawning season.

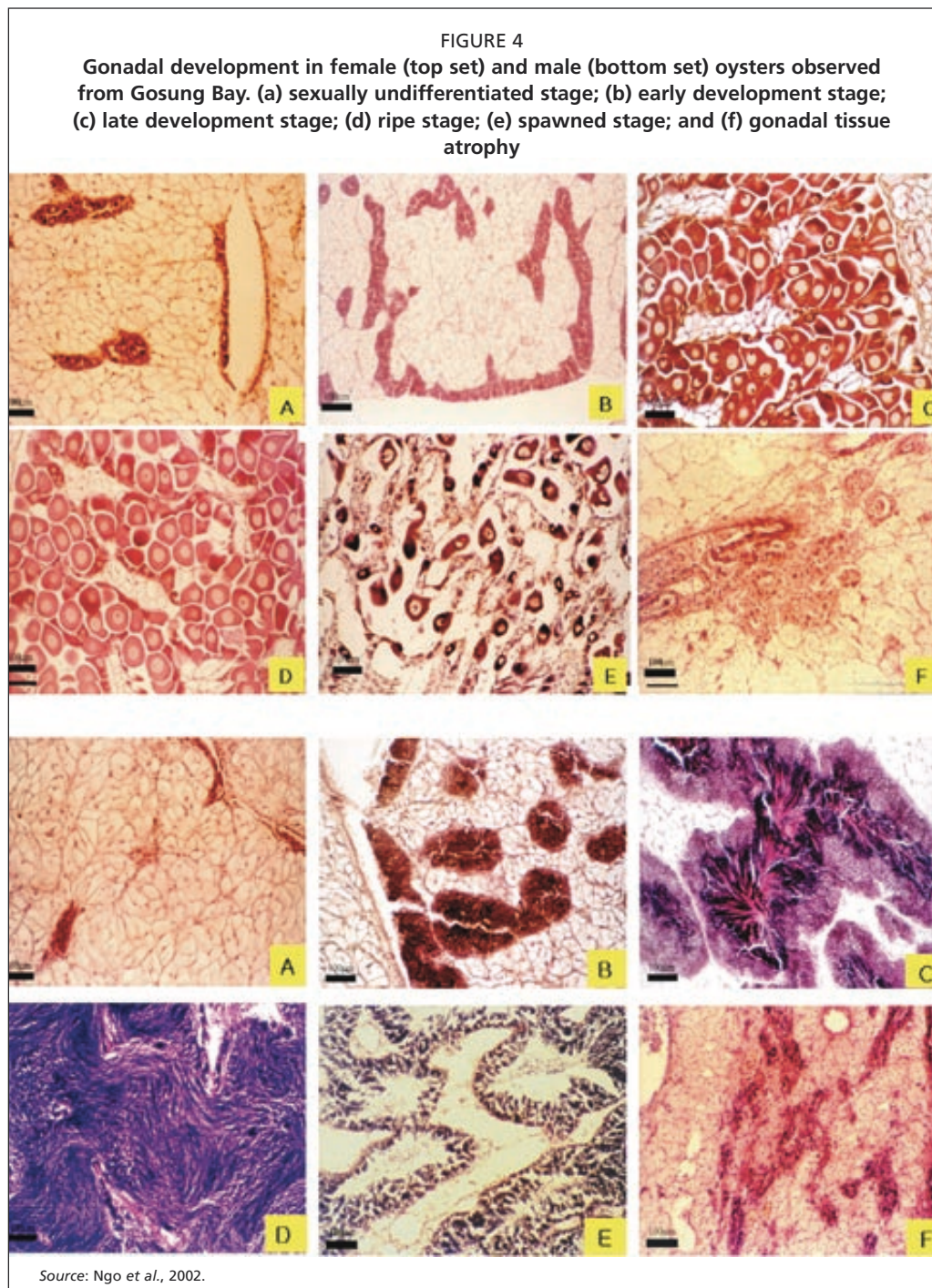
Larval development

Figure 6 shows the development of the trochophore stage from the pear-shaped mature oocytes released from spawning oysters. The first polar body forms between 50 to 70 minutes after fertilization when water temperature ranges from 20–21 °C. The morula stage can be observed 3 or 3.5 hours after fertilization, while the rotating blastula larva appears between 5 and 6 hours following hatching. Fifteen to twenty-eight hours after fertilization the oyster D-shape larvae develops and, depending on the water temperature, the fully grown larvae (300–350 µm) appear in the water column 10 to 20 days after fertilization and subsequently settle on fixed substrates (Figure 7).

Temperature and salinity are the two key environmental factors that govern larval development. Numerous studies have demonstrated that low water temperatures and salinities slow down larval development, while higher temperatures shorten the duration of the larval period. According to Yoo and Yoo (1972), it takes approximately 10 days from fertilization to settlement when the water temperature remains above 27 °C. However, it takes more than 3 weeks from the fertilized egg to settlement when the water temperature ranges between 19–20 °C.

CURRENT STATUS OF OYSTER AQUACULTURE

During the 1960s and 1980s, oyster production in the Republic of Korea increased dramatically due to the introduction of suspended culture techniques, which enabled the oyster farmers to extend their farming area from intertidal areas in the bays to deeper waters in the middle of the bay. In the early 1960s, Korean oyster production remained below 20 000 tonnes, however, production increased exponentially from 1965 to 1987; in 1985 production reached its peak at 288 078 tonnes (Figure 8). During the 1990s and early 2000, the annual oyster production remained stable, between 170 000

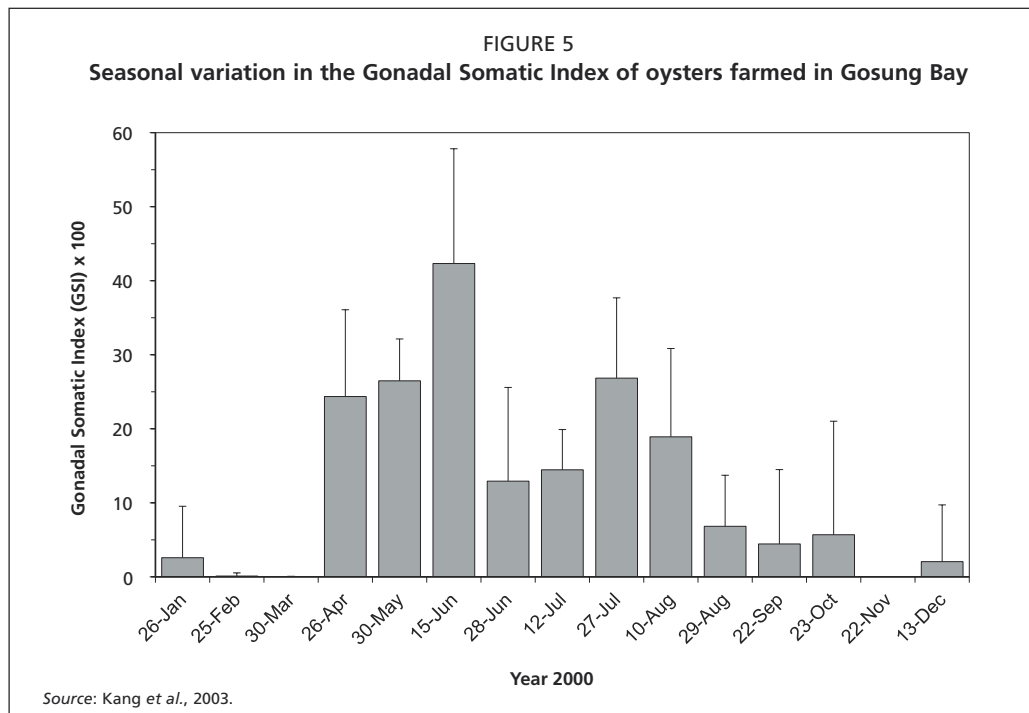


to 250 000 tonnes. Figure 9 plots the value (in US\$) of the Korean oyster production from 1985 to 2005. The value decreased dramatically in 1998 due to the drop of the foreign exchange rate brought about by the economic crisis in the Republic of Korea.

In 2005, over 251 706 tonnes of shell-on oysters were produced (or 37 756 tonnes of oyster meat), valued at US\$128 269 million. In this same year, an additional 27 320 tonnes of oysters were harvested from natural banks, accounting for approximately 10 percent of the total national production.

OYSTER CULTURE PROCEDURES

The process of oyster aquaculture includes: 1) seed production (collection of natural spat or artificial spat production from hatchery); 2) hardening (i.e. stunting); 3) grow-out; and 4) harvest (Figure 10).



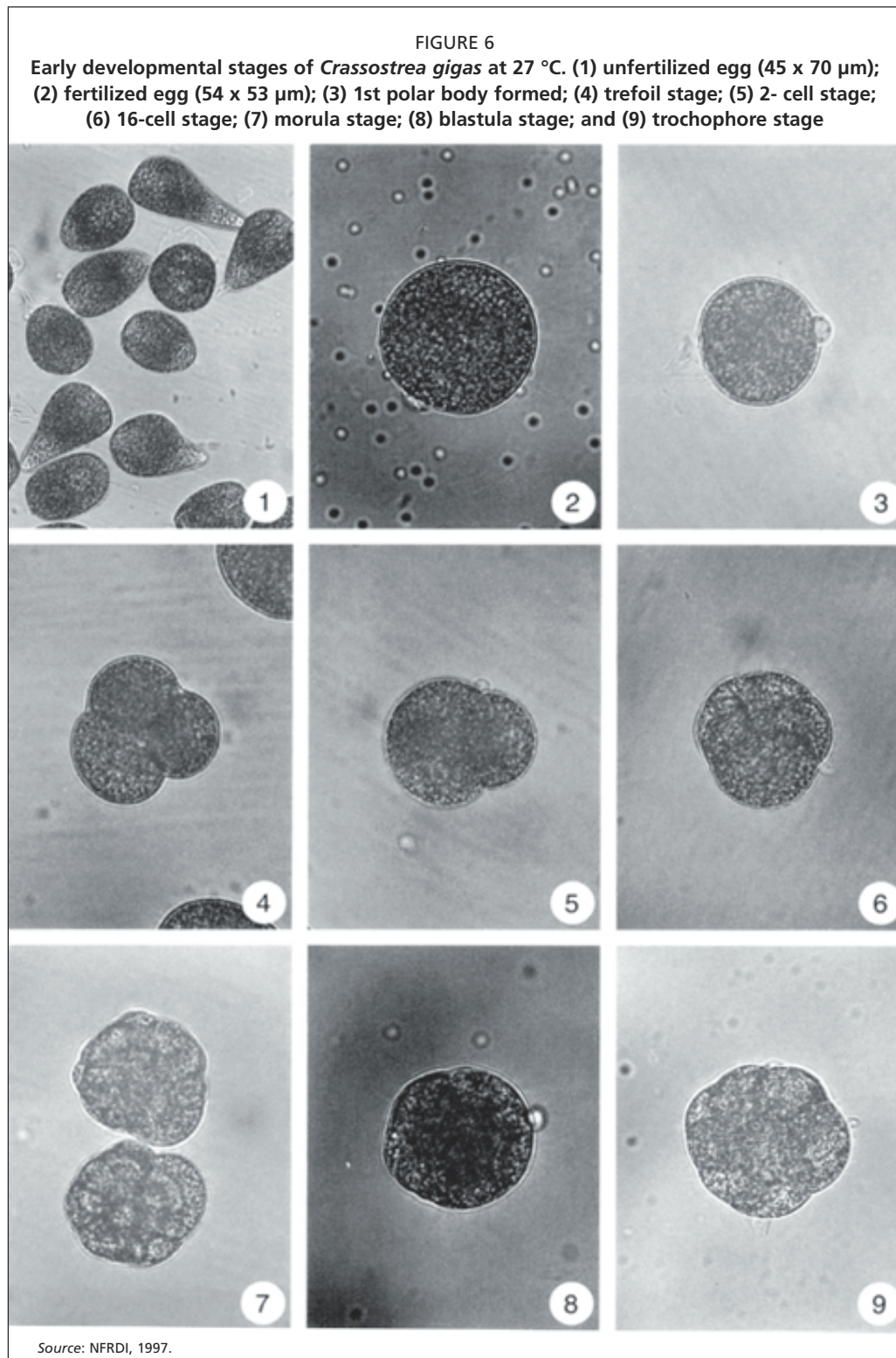
Seed production phase

Obtaining a sufficient quantity of healthy larvae is essential to support successful oyster production. The Korean oyster industry mainly relies on the collection of natural spat. According to the Korean Oyster Longline Culture Cooperative, natural spat supply 90 percent of the national oyster seed demand, while hatchery-produced seed provide the remaining 10 percent. As shown in Figure 3, mature oysters spawn as early as mid-May and continue to do so until the end of September. Depending on key environmental parameters, such as water temperature, salinity and food availability, the larvae settle 10–20 days after fertilization.

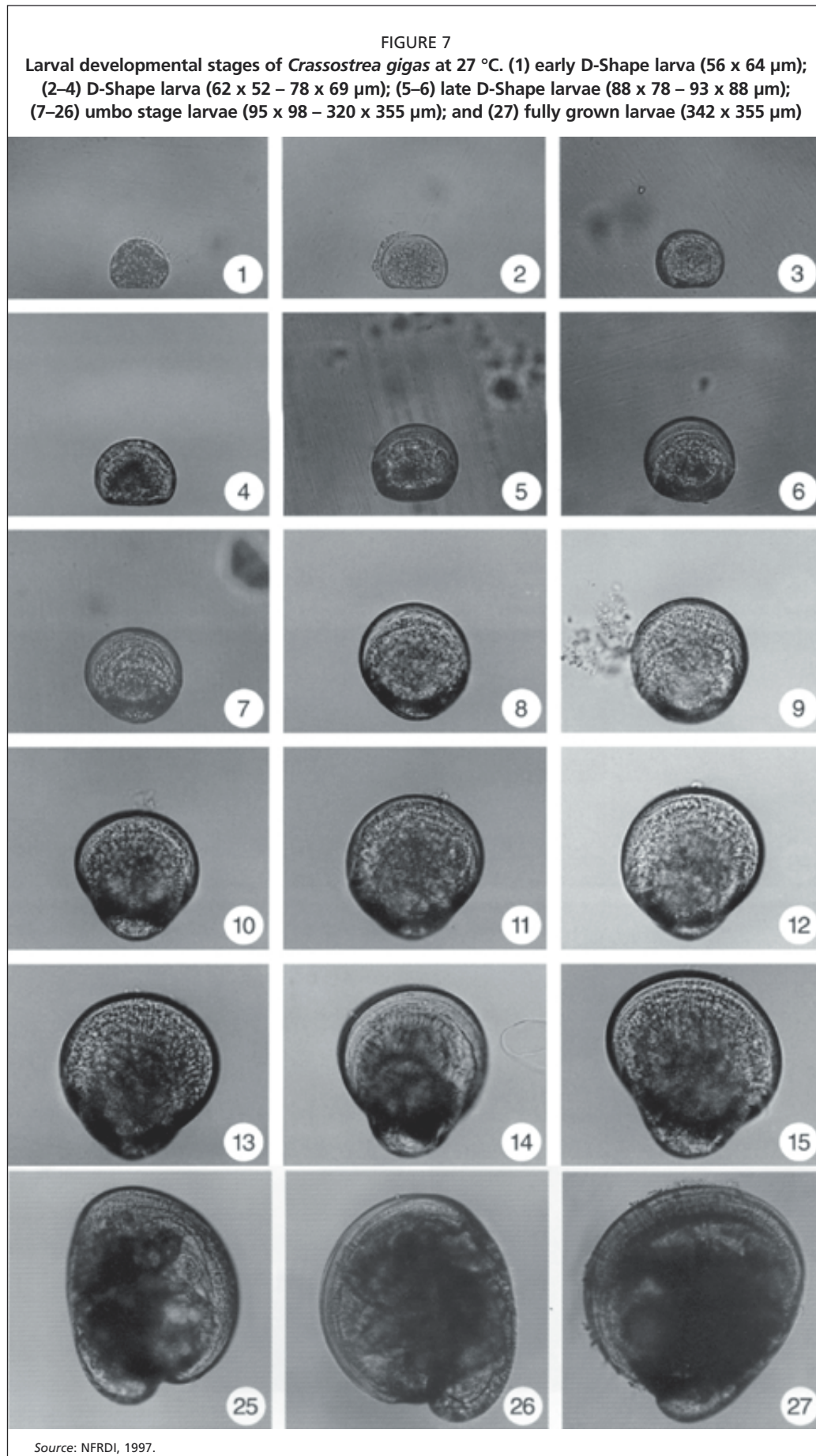
To ensure the collection of a large number of spat, the abundance and development stage of the larvae in the water column are routinely monitored by the regional marine extension services. The monitoring data, including information on the expected maximum oyster spat-fall period, are then conveyed to the oyster growers. Furthermore, an “oyster larval-forecasting” newsletter is posted on specific websites on a weekly basis from mid-May to end August. In the meantime, oyster growers prepare the spat collectors and place them at sea when the abundance of the larvae is at its highest value.

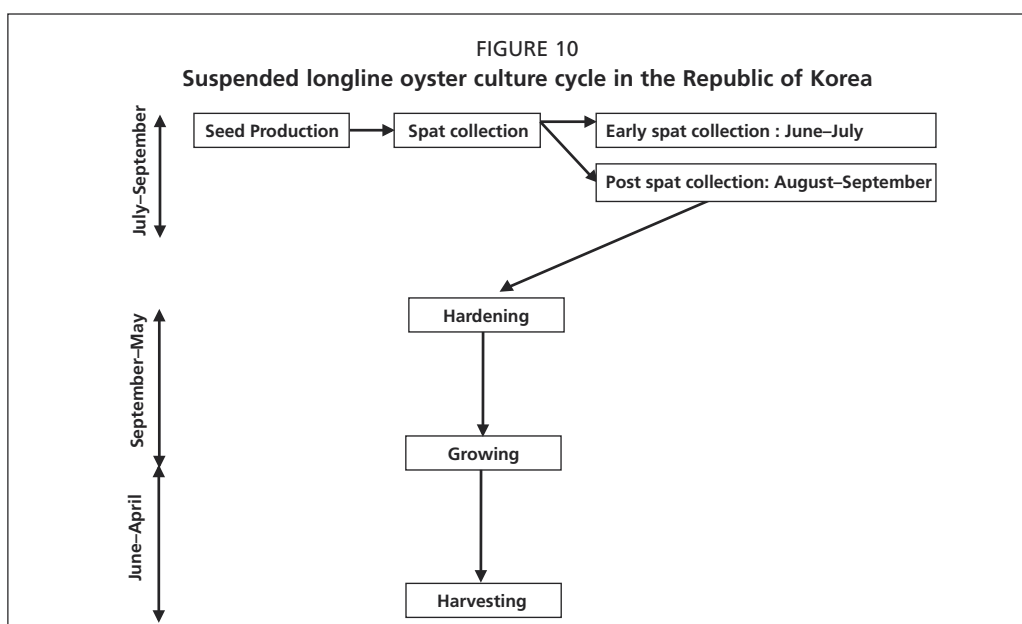
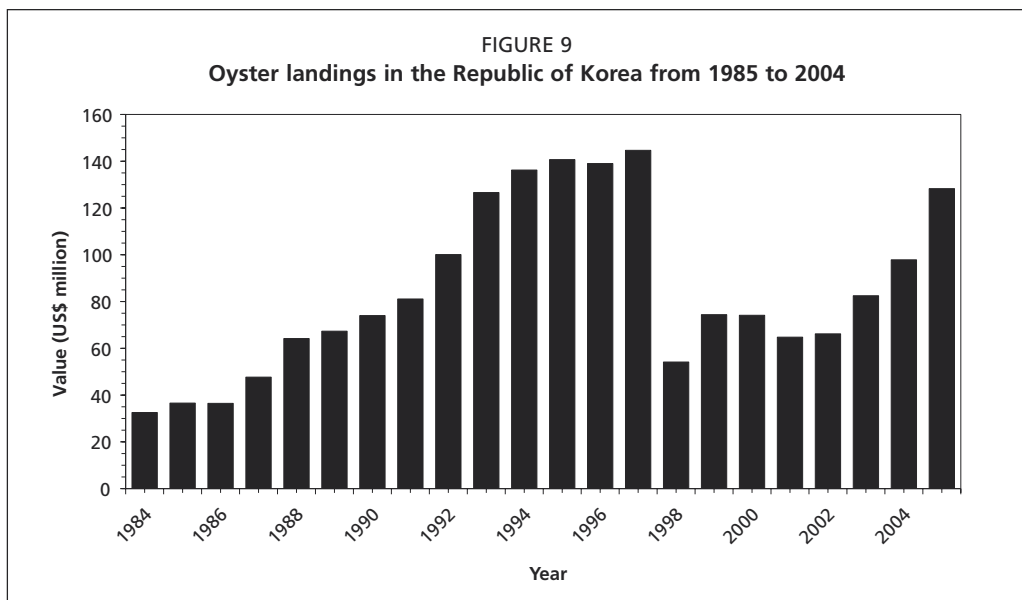
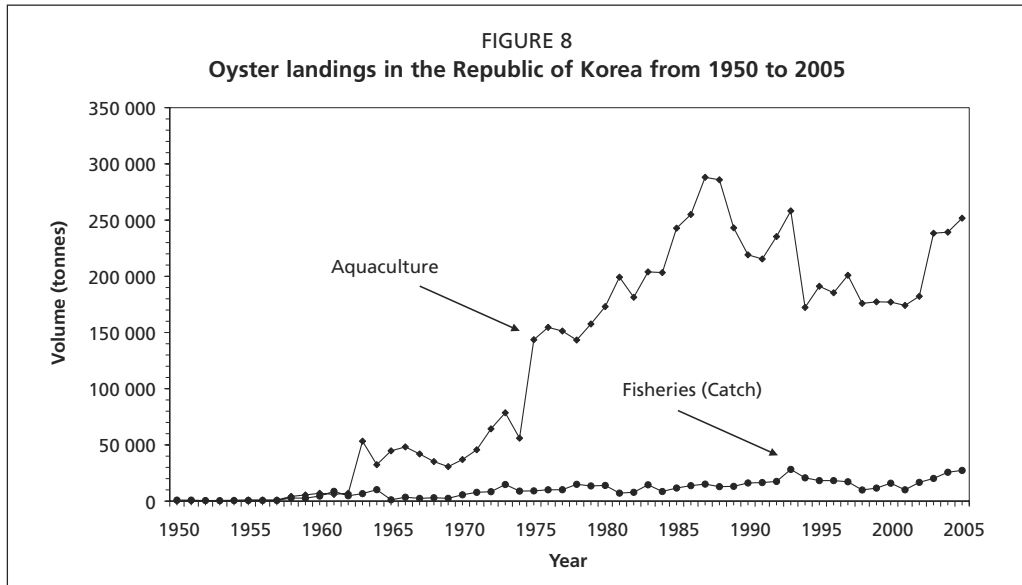
Adult oyster or scallop shells are used as substrate (i.e. cultch) for the larvae to settle on. A spat collector is prepared by first piercing a hole in the middle of the dead oyster or scallop shell and then stringing 50–60 pieces on a 1.5–2 m plastic line (Figure 11). Oyster spat are traditionally collected from the intertidal zone by suspending the collectors on wooden racks which are periodically exposed for 2–3 hours during low tide (Figure 12). Spat can also be collected from subtidal areas by submerging the collectors from the boat. The optimal spat density for each cultch (i.e. oyster or scallop shell) is considered to be 30 spat per single oyster shell or 40–50 spat for each scallop shell.

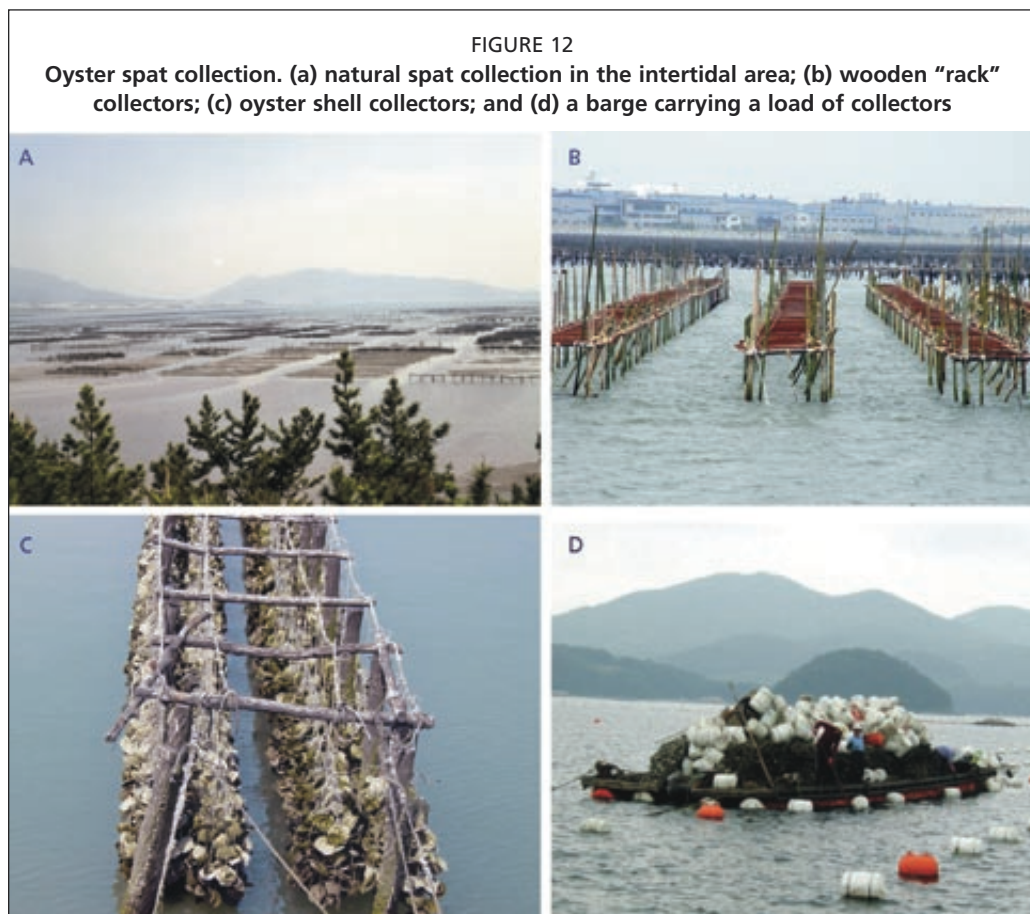
To ensure the availability of the required volume of seed, both “early spat” collection (June–July) and “late spat” collection (August–September) are targeted by the industry. In 2005, the early spat collection effort started in early June and continued till the end of June, during which time 5.5 million oyster seed collectors were utilized to collect the spat. In 2005, a total of 14.1 million oyster spat collectors were used indicating that spat settlement was more intense during late summer (late spat period).



More recently oyster seeds have also been used from private hatcheries located on the south coast. The conditioning of broodstock allows hatchery operators to start seed production as early as February and complete the production before the natural spat collection begins. In 2005, approximately 3 percent of the oyster spat demand was supplied from private hatcheries. Spat are also imported from Japan and the United States of America. For example, in 1997 almost 16 percent of the national spat demand was supplied from hatcheries in the United States of America due to poor natural harvest that supplied only 70 percent of the industry requirement (Han, 2005).







Hardening phase

Ten days after settlement, the oysters attached to the collectors are transferred to the hardening ground, or directly to the longline culture system for grow-out. Since hardened oysters have a better survival rate, the oyster growers routinely undertake this culture phase. Hardening the seed oysters takes place in the intertidal zone where the area is exposed for 6–8 hours during the tidal cycle. As shown in Figure 13, a series of wooden racks are built in the intertidal area from where the collectors are suspended. The hardening period begins in September and continues until the following April, during which the seeds are periodically exposed to the atmosphere during low tide to eliminate unhealthy and weak individuals. In May, the hardened seed oysters reach



1–1.5 cm in shell height and are ready for grow-out. At the end of the hardening period, the number of spat initially settled on the shell surface (40–60 spat/shell) drops to 20–30/shell. The stunted oyster seeds tend to grow faster and show a high survival rate during grow-out.

Grow-out phase

Approximately 90 percent of the Korean oysters come from farms located in small bays and off islands along the south coast. Figure 14 shows the location of the 7 major oyster culture sites in the south, where 258 oyster leases utilize approximately 1 983 hectares of sea surface for grow-out activities. These areas are protected, shallow (5–20 m deep) and have a high primary productivity. The oyster farms along the south coast exclusively use the longline culture system. The oyster strings are suspended on a submerged longline which is supported by numerous buoys (Figure 15).

In May, the hardened seed oysters collected from the previous summer reach 1–1.5 cm in shell height. For grow-out, the hardened seed oysters attached on the clutches and suspended on the hardening racks are harvested and the seed strings are disassembled for longline culture. Using a plastic wire ($\phi=3.8$ mm) each cultch (i.e. oyster or scallop shells containing the hardened seed oysters) is strung on the wire at 20 cm intervals. The 5 m long oyster grow-out string may include 20–25 cultch.

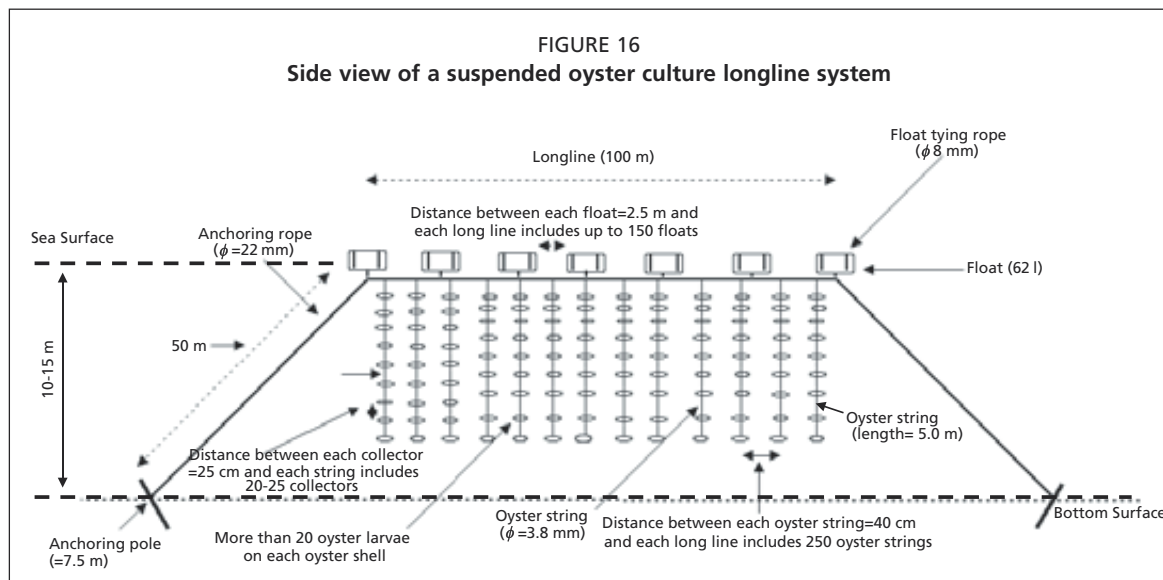
Figures 16 and 17 illustrate a schematic view of a longline oyster grow-out facility. Each longline is a 100 m long rope ($\phi=22$ mm) kept afloat by as much as 150 buoys (62 litres). On each longline, 200–250 strings of the hardened seed oysters are suspended. The grow-out for the seed oysters lasts for 6–10 months before harvest. During the grow-out period, the oyster seeds grow to 8–12 cm in shell height or 9–15 g in tissue wet weight (Han, 2005).

FIGURE 14
Map showing the major oyster farming regions off the south coast of the Republic of Korea



FIGURE 15
Fields of farmed oysters using suspended longlines



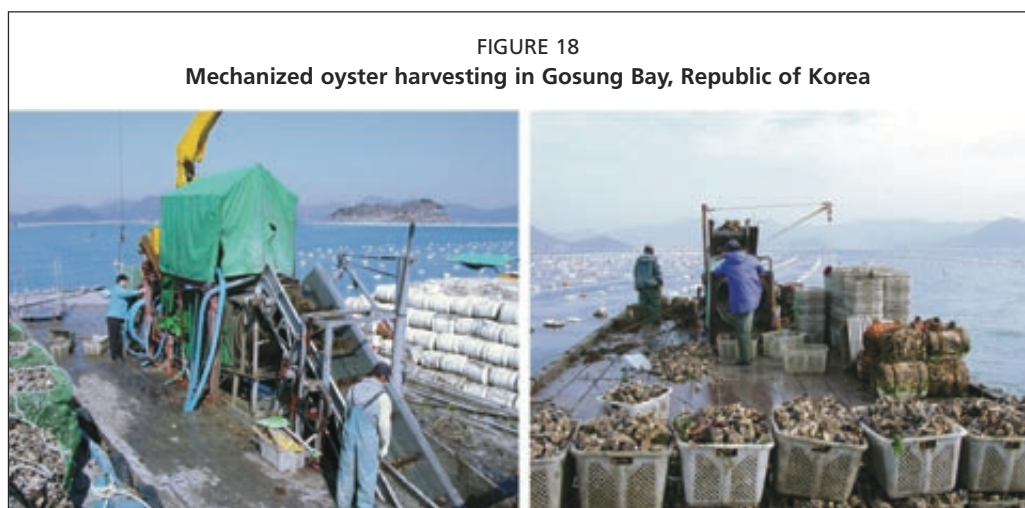


Harvest

On the south coast, harvesting oysters from the longline begin as early as in September and the harvesting continues until the following April. The oyster strings suspended from the longline are lifted onto a work boat with the use of a winch installed on the side of the vessel. The oyster strings are then cut on the deck and dumped into plastic containers and sent to the local shucking factory (Figure 18). After several freshwater washing cycles the oysters are shucked and the flesh washed again with sterilized seawater before it is sorted by size for sale and further processing (Figure 19).

SOCIO-ECONOMIC ASPECTS OF KOREAN OYSTER CULTURE

As shown in Figure 14, the southern coast of the Republic of Korea is characterized by numerous small bays and islands and extensively utilized for oyster longline aquaculture. The coastal area off the two provinces of Gyeongsangnamdo and Jeonranamdo covers



7 districts and 34 385 hectares of sea surface. In 2005, a total of 784 oyster leases were issued by the Ministry of Maritime Affairs and Fisheries and the oyster farms located along the south coast utilized 4 479 hectares of sea surface (Table 2). Currently 90 percent of the total annual oyster landings are produced from longline culture in the south. In 2005, it was estimated that 226 535 tonnes of shell-on oysters (33 980 tonnes

TABLE 2
Number of leases, farm area, longlines and oyster strings in two southern provinces in the Republic of Korea in 2005

Province	Culture area	Number of leases	Area (ha)	Number of longline	Number of oyster strings
Gyeongsangnamdo	Dosan Bay	89	439	7 651	1 910 000
	Saryang Bay	40	189	3 374	843 000
	Sanyang Bay	29	113	1 737	434 000
	Hansan Bay	32	152	1 235	308 000
	Jinhae Bay	183	825	15 609	3 820 000
	Geoja Bay	67	542	6 545	1 608 000
	Chilchung Island	33	166	3 119	779 000
	Gosung Bay	18	66	1 057	274 000
	Jaran Bay	135	747	12 497	3 140 000
	Masan Bay	30	128	2 261	584 000
	Namhae	27	164	2 906	1 048 000
Jeonranamdo	Gamakman Bay	101	948	11 930	4 167 000
	Goheung				
	Gangjin				
Total		784	4 479	69 921	19 015 000

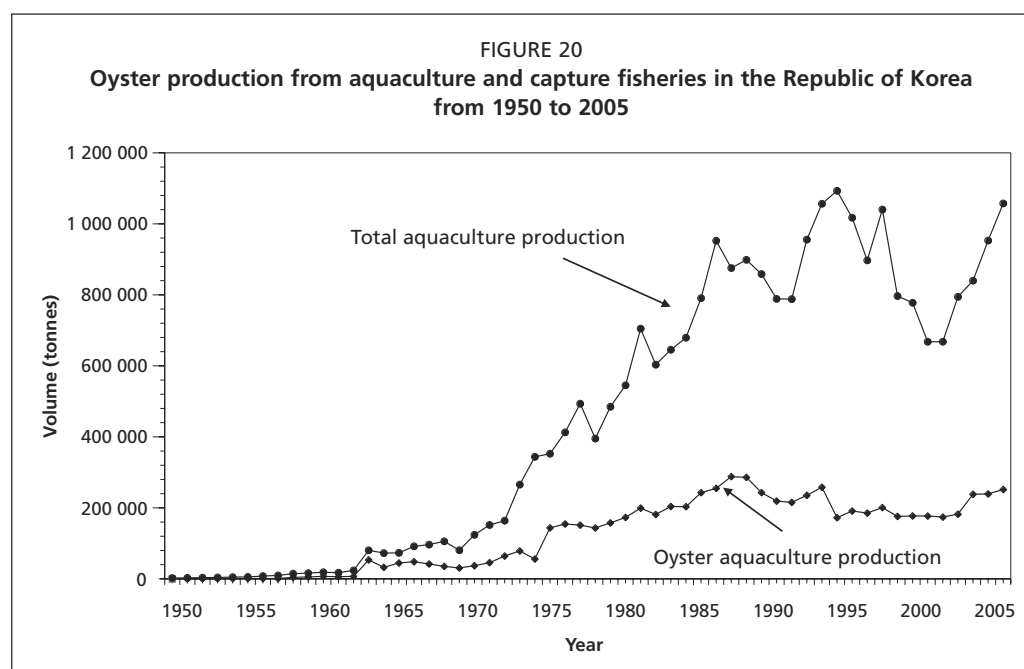


TABLE 3
Quantity and value of oysters exported from 2002 to 2004

Year	2002		2003		2004	
	Quantity (tonnes)	Value (US\$)	Quantity (tonnes)	Value (US\$)	Quantity (tonnes)	Value (US\$)
Fresh Meat	3 143	16 316 000	2 813	14 225 000	2 222	12 585 000
Frozen	7 215	26 852 000	7 057	27 360 000	7 010	33 139 000
Canned	6 155	27 729 000	6 031	26 947 000	4 919	25 138 000
Other	704	5 225 000	710	6 165 000	510	5 778 000
Total	17 217	76 122 000	16 611	74 697 000	14 661	76 640 000

of oyster meat) were produced. From 2000 and 2005, oyster landings accounted for 23–28 percent of the total national aquaculture production (Figure 20).

According to the authorities of Gyeongsangnamdo Province, in 2005 approximately 3 000 families were engaged in oyster farming over an area covering 3 622 hectares while a further 406 families were involved in the industry off the southwest coast of Jeonranamdo Province. The Korean oyster longline culture cooperative estimates that there are 22 000 full-time employees engaged in the oyster industry from farming to processing.

The majority of the Korean oysters are exported to Japan and the United States of America. Table 3 lists the type of products exported, their quantity and value. In 2002 and 2004, 14 661 to 16 611 tonnes of oysters were exported, accounting for almost 41 to 63 percent of the total production.

In 2003, the Korean Fisheries Economic Institute analyzed the economic status of selected oyster farming companies. According to the study, an average oyster farm in Tongyoung operated 126 longlines for a grow-out period lasting 172 working days. Furthermore, the farm owner hired no permanent employees, but only temporary workers (\approx 230 persons). The production from one farm averaged 297 tonnes worth approximately US\$134 000. The net profit was calculated at around US\$33 000 (excluding wages, equipment repair and maintenance, and seed cost).

ENVIRONMENTAL IMPACT OF OYSTER LONGLINE CULTURE

Intensive oyster longline culture in small bays off the southern coast often resulted in anoxia on the sea bed due to the accumulation of pseudofaeces from the suspended oysters. These anoxic problems were more prominent in bays where the seawater

circulation was poor. Furthermore, the high density of oysters on the longlines also results in poor growth and, subsequently, poor profits. To overcome these problems, the distance between oyster farms, the distance between longlines and the number of suspended oyster strings on an individual longline has been regulated as shown in Figures 16 and 17. The regional office of marine extension and the oyster longline culture cooperatives provide information on the proper management of oyster farms, such as a standard model of longline culture system, through a newsletter and on the website. For example, the original styrofoam floats used in the longline culture which could not be disposed off have been replaced by the more durable and environmental friendly plastic floats.

ACKNOWLEDGEMENTS

Thanks go to the Korean Oyster Longline Culture Cooperatives in Tongyoung for granting permission to use the photos and data presented. Bongkyu Kim and Yanin Limpanont are also acknowledged for their help in preparing the figures in this report.

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Annex 1 – Workshop agenda

**FAO INTERNATIONAL WORKSHOP ON
TECHNICAL GUIDELINES FOR THE RESPONSIBLE USE OF WILD FISH AND
FISHERY RESOURCES FOR CAPTURE-BASED AQUACULTURE PRODUCTION
Hanoi, Viet Nam, 8–12 October 2007**

AGENDA AND TIMETABLE

Monday, 8 October 2007

opening Session

08:00 – 08:30	Arrival and registration
08:30 – 09:00	Opening remarks Introduction of experts
09:00 – 09:15	Adoption of Agenda

Introduction

09:15 – 09:30	Introduction of Technical Guidelines
09:30 – 10:00	General discussion
10:00 – 10:30	<i>Coffee/Tea</i>

Presentation Session I – Reviews

10:30 – 11:00	Environmental and biodiversity impacts of CBA – Y. Sadovy
11:00 – 11:30	Social and economic impacts of CBA – R. Pomeroy
11:30 – 12:00	General discussions

Presentation Session II – Species Papers

12:00 – 12:15	Pangasiids and snakehead – A. Poulsen & D. Griffiths
12:15 – 12:30	<i>Clarias</i> catfish – V. Poumogne
12:30 – 14:00	<i>Lunch</i>
14:00 – 14:15	Mullet – M. Saleh
14:15 – 14:30	Indian major carps – M. Rahman
14:30 – 14:45	European eel – P. Prouzet
14:45 – 15:00	Atlantic bluefin tuna – F. Ottolenghi
15:00 – 15:15	Cod – K. Midling & Ø. Hermansen
15:15 – 15:30	Yellowtail – M. Nakada
15:30 – 16:00	<i>Coffee/Tea</i>
16:00 – 16:15	Grouper – M. Tupper
16:15 – 16:30	Mud crab – C. Shelley
16:30 – 16:45	Oysters – K. S. Choi
16:45 – 17:45	General discussion

Tuesday, 9 October 2007

Session III – Working Groups

08:30 – 10:00	Draft guidelines status and setting up of working groups - Secretariat
10:00 – 12:30	Working Groups discussions and drafting
12:30 – 14:00	<i>Lunch</i>
14:00 – 16:00	Working Groups discussions and drafting
16:00 – 17:30	Working Groups presentations and plenary discussions
19:30 – 21:30	Official dinner

Wednesday, 10 October 2007

Session III – Working Groups (continued)

08:30 – 09:00	Plenary summary and presentation of key themes/status of draft guidelines
09:00 – 12:30	Working Groups discussions and drafting
12:30 – 14:00	<i>Lunch</i>
14:00 – 17:00	Technical ½ day field trip

Thursday, 11 October 2007

Session III – Working Groups (continued)

08:30 – 09:00	Plenary summary and presentation of key themes/status of draft guidelines
09:00 – 12:30	Working Groups discussions and drafting
12:30 – 14:00	<i>Lunch</i>
14:00 – 16:00	Working Groups discussions and drafting
16:00 – 17:30	Working Groups presentations and plenary discussions

Friday, 12 October 2007

Session IV – Plenary discussions

08:30 – 10:00	Plenary summary and presentation of key themes/status of draft guidelines
10:00 – 12:30	Working Groups discussions and drafting
12:30 – 14:00	<i>Lunch</i>
14:00 – 15:30	Plenary discussions on workshop achievements and way forward
15:30 – 16:00	<i>Coffee/Tea</i>
16:00 – 17:00	Final discussion and closing ceremony

Annex 2 – List of participants

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Annex 3 – Expert profiles

FUNGE-SMITH, Simon – Mr Funge-Smith qualified as a Marine biologist from the University of Liverpool (United Kingdom) and completed his Doctorate at the Institute of Aquaculture, University of Stirling (Scotland, United Kingdom) in the area of tropical aquaculture. His postdoctoral work (1991–1994) was based heavily in the field in Thailand working on environmental and management aspects of brackishwater shrimp aquaculture. He worked for two years (1995–1997) as a consultant based in Asia working in China, Malaysia, Sri Lanka, Bangladesh, Philippines and Thailand. Several of the assignments were for FAO. In 1997, he joined FAO as a Chief technical advisor to an aquaculture development project in the Lao People's Democratic Republic working in rural extension of aquaculture. Following the closure of the project, he briefly worked with the Mekong River Commission as a consultant before taking up his current post as Aquaculture Officer into the FAO Regional Office in Bangkok. His responsibilities span 40 Member countries in the Asia-Pacific Region and he has travelled, for work reasons, in over 22 of these. His work covers project development management as well as the work of the Asia-Pacific Fishery Commission. Some key areas of work that he has been involved in are the use of low value and trash fish for aquaculture, co-management mechanisms, inland fisheries management, aquaculture certification, and routine analysis of the aquaculture and fisheries of the Asia-Pacific Region.

GRIFFITHS, Don – Mr Don Griffiths has over 20 years of experience in fresh, brackish and marine aquaculture development and extension primarily in Asia (Bangladesh, Cambodia, India, Lao People's Democratic Republic, Malaysia, Thailand, Viet Nam), but also Fiji, Lesotho and Mozambique, working for a variety of donor agencies including Overseas Development Agency (ODA), United Kingdom Department for International Development (DFID), Danida, United States Agency for International Development (USAID), the European Union (EU) and Mekong River Commission. Mr Griffiths is currently working as the Senior Advisor for the Government of Viet Nam–Danida funded Sustainable Development of Aquaculture (SUDA) component under the Fisheries Sector Programme Support Phase II (FSPS II). The FSPS II will run to the end of 2010.

HERMANSEN, Øystein – Mr Hermansen presently conducts applied research on the economics of capture-based aquaculture operations in Norway, particularly on the Atlantic cod. This involves research on the private and full cost profitability and also factors which hinder fishermen in undertaking this activity. In addition, he collaborates on projects to investigate the bioeconomics of various capture-based aquaculture fisheries, intending to identify properties that define the profitability of this aquaculture practice. He has also worked on capacity issues in fisheries and was the secretary for a National Advisory Panel for Capacity Reduction in Norwegian Fisheries. Mr Hermansen has an MSc degree in Fisheries and Aquaculture from the Norwegian College of Fisheries Science, University of Tromsø, Norway obtained in 2002.

HOLTHUS, Paul – Dr Holthus's work is focused on achieving sustainable development of marine and coastal areas and the sustainable use of marine resource and sustainable livelihoods, with an emphasis on bringing together the private sector and the environmental concerns to realize solutions. His experience ranges from working

with the directors of United Nations (UN) agencies on international ocean policy to working with fishermen in small island villages. He has been involved in coastal management and marine resource conservation and sustainable use in over 30 countries in Asia, the Pacific, Central America, and West Africa. From 1998–2007, Paul was the founding Executive Director of the Marine Aquarium Council (MAC). MAC is an international standards-setting, certification and capacity-building organization for sustainability of the global marine aquarium fishery and trade, including aquaculture. MAC has built a global multi-stakeholder network of the marine aquarium industry/fishers, conservation groups, public aquariums, international organizations and government agencies; developed international standards of best practice for certification of the communities, companies, culturing facilities and chain of custody in the marine ornamentals industry; and created industry and consumer demand for MAC Certified marine ornamentals. Past senior positions have included: Deputy Director, Global Marine and Coastal Programme, The World Conservation Union (IUCN); Senior Programme Officer, Asia-Pacific Marine Programme, The Nature Conservancy; and Senior Programme Officer, South Pacific Regional Environment Programme (SPREP, part of the UN Environment Programme's Regional Seas Organizations), as well as international projects as an independent consultant. He is a graduate of the University of California and the University of Hawai'i.

KWANG SIK, Choi – Dr Kwang Sik has been working since 1995 as a professor at the School of Applied Marine Science, Cheju National University. Apart from his teaching obligations in aquaculture Dr Kwang Sik's main area of interest is bivalves. His applied research work focuses on shellfish disease diagnosis, culture and ecology. Prior to joining the University, he worked for a few years as Senior Researcher at the Korean Institute of Nuclear Safety during which time he was involved in inspecting environmental safety of thermal effluents from nuclear power plants. Dr Kwang Sik obtained his both his MSc (1987) and his PhD (1992) in Oceanography at the Texas A&M University, United States of America.

LOVATELLI, Alessandro – Mr Lovatelli, a trained marine biologist and aquaculturist, obtained his Bachelor (BSc) and Master of Science (MSc) degrees at the universities of Southampton and Plymouth (UK), respectively. His first experience with FAO dates back to 1987 working as the bivalve expert attached to an FAO/United Nations Development Programme (UNDP) regional project. His subsequent FAO assignment was in Mexico working on a regional aquaculture development project (AQUILA) funded by the Italian Government. From 1993 to 1997 he worked in Viet Nam, Somalia and then again in Southeast Asia. In Viet Nam he headed the aquaculture and fisheries component of a large European Union project developing, among other activities, 10 regional aquaculture demonstration, training and extension centres. In Somalia he acted as the lead aquaculture and fisheries consultant for the European Commission. Following an additional year in Viet Nam as one of the Team Leaders under the Danish-funded Fisheries Master Plan Project, Mr Lovatelli was recruited by FAO as the Aquaculture Advisor attached to the FAO-EASTFISH project based in Denmark. In 2001 Mr Lovatelli once again joined the FAO Fisheries and Aquaculture Department. The main activities currently focused on are marine aquaculture development, transfer of farming technologies and resources management. Mr Lovatelli has coordinated and co-authored an FAO review on capture-based aquaculture (CBA) published by FAO in 2004.

MIDLING, Kjell – Mr Midling is a specialist in capture-based aquaculture and has worked for the Norwegian Institute of Fisheries and Aquaculture Research since 1988. Fish behaviour, fish communication (sound) and fish preferences have played a major part of his research, dealing both with technological developments and studying their

behaviour *per se*. He is an inventor on patents involving cage constructions (flat-bottom cages for species without a gas-bladder) and feeding system (submerged “intelligent” feeding). He has been involved in a large number of projects nationally and abroad both within aquaculture and fisheries varying from fishing gear, live transportation, cages for restitution, slaughter technologies, fish welfare and quality. He was scientist in charge of the first offshore farm in Hainan, People’s Republic of China (1997–99) and has hands-on experiences in commercial fisheries and aquaculture. He has been a member of several scientific commissions, including 12 years in the Norwegian Research Council.

NAKADA, Makoto – In his present position Mr Nakada provides technical advice on marine aquaculture and fisheries to the Japanese industry as well as to developing countries under a cooperation scheme of the Tokyo University of Marine Science and Technology. In particular Mr Nakada provides advice on fish nutrition and feed formulation, water treatment for aquaculture, and farming techniques. Mr Nakada has worked extensively on Yellowtail aquaculture in Japan and abroad and has published numerous papers and reports including “Yellowtail Aquaculture in Japan, Handbook of Mariculture (CRC Press Inc.), “Yellowtail and Related Species Culture, Encyclopedia of Aquaculture” (John Wiley & Sons), and “Yellowtail culture development and solutions for the future, Aquaculture Growout System, Challenges and Technological Solutions (CRC Press Inc.).

OTTOLENGHI, Francesca – For almost a decade Ms Ottolenghi has been engaged in projects in the field of aquaculture and related subjects. As a project leader she coordinated scientific tuna projects financed by the Italian Ministry of Agriculture and by the European Commission (EC). She has participated as a tuna expert in the Italian delegation at meetings organized by the International Commission for the Conservation of Atlantic Tunas (ICCAT) as well as acted as “Chair” of the tuna session at the 2006 World Aquaculture Society Conference held in Bali, Indonesia. Ms Ottolenghi actively participated in the “Working Group on Sustainable Bluefin Tuna Farming/Fattening Practices in the Mediterranean” jointly set up by the General Fisheries Commission for the Mediterranean (GFCM) and ICCAT. She is the main author of an FAO report entitled “Capture-based aquaculture”. Ms Ottolenghi is presently working for Halieus, an Italian non-governmental organization (NGO) conducting international cooperation projects in the field of fisheries and aquaculture.

PHAM, Anh Tuan – Dr Pham Anh Tuan is currently the Deputy Director in charge of research and training at the Research Institute for Aquaculture No. 1 (RIA 1) located in the vicinity of Hanoi. He obtained a BSc at the University of Fisheries in Nha Trang (Viet Nam) in 1977 and a MSc in Aquaculture at the Asian Institute of Technology (AIT), Bangkok, Thailand, in 1992. He obtained his PhD at the University of Wales Swansea (UK) in 1997 working on sex ration control of Nile tilapia. The main fields of expertise of Dr Pham An Tuan are fish breeding and genetics based on the fact that he has been working on gene bank development of fish by application of sperm cryopreservation, genetic improvement of rohu and mrigal, selective breeding of tilapia for saline aquaculture, development of all male tilapia and prawn, introduction of aquatic species in Viet Nam, etc. He has worked extensively as a national aquaculture consultant for projects funded by the Asia Development Bank (ADB), United Nations Development Programme (UNDP), the Food and Agriculture Organization of the United Nations (FAO) and other development organizations (e.g. DANIDA, DFID, IFAD). His experience ranges from project formulation and evaluation. Dr Pham Anh Tuan has coordinated a national project on improving freshwater fish seed supply and performance in small-holder aquaculture systems in Asia. This project evaluated the

state of hatchery systems in Viet Nam with the objective of developing a seed supply strategy for smallholder aquaculture systems. The project also looked for approaches to improve performance of existing hatcheries and seed distribution networks.

POMEROY, Robert – Dr Pomeroy is currently an Associate Professor in the Department of Agricultural and Resource Economics and Connecticut Sea Grant College Fisheries Extension Specialist at the University of Connecticut – Avery Point in Groton. Before starting at the University of Connecticut in August 2002, Dr Pomeroy worked at the World Resources Institute in Washington DC from September 1999 to December 2001 where he helped develop a marine programme. Prior to that, he worked at the International Center for Living Aquatic Resources Management (ICLARM) in Manila, Philippines from 1991 to 1999. From 1984 to 1991, Dr Pomeroy was on the faculty of Agricultural and Applied Economics at Clemson University in South Carolina. Dr Pomeroy holds a PhD in Resource Economics from Cornell University. His areas of professional interest are marine resource economics and policy, specifically small-scale fisheries management and development, coastal zone management, aquaculture economics, international development, policy analysis, and seafood marketing. Dr Pomeroy has worked on research and development projects in over 40 countries in Asia, Africa, the Caribbean and Latin America. He is a Senior Research Fellow at the WorldFish Center headquartered in Penang, Malaysia.

POULSEN, Anders – Mr Poulsen currently works as an Adviser to the Ministry of Agriculture and Rural Development (MARD) and provincial fisheries departments (DOFI) in Viet Nam on the sustainable management of capture fisheries in both marine/coastal and inland waters, a programme founded by Danida. He is also engaged in co-management pilot activities in the Mekong Delta, where the pangasiid catfish culture is extremely important. Mr Poulsen started his overseas career as an associate professional officer (APO) with FAO on a river fisheries project in the Sepik River in Papua New Guinea in 1991. He has been working for the Mekong River Commission (MRC) in the Lao People's Democratic Republic as a Technical Adviser for the fisheries programme, particularly focusing on fisheries ecology and assessment in the lower Mekong basin. He worked in Bangladesh on two assignments: recently as Team Leader and Inland Biodiversity Expert for the Aquatic Resources Development, Management and Conservation Studies under the Fourth Fisheries Project (funded by World Bank/GEF), and prior to this as a Training and Extension Adviser for an aquaculture extension project (funded by Danida). He also worked as Biodiversity Expert with the Caspian Environment Program in Tehran, Iran Islamic Republic.

POUOMOGNE, Victor – Since 2004, Dr Poumogne has been carrying out research work in collaboration with agrofishers within Santchou valley, who use African catfish fingerlings (*Clarias* spp.) from the wild for aquaculture purpose. Since 1995, he has been fully involved in tropical aquaculture and fisheries programmes aiming at spreading scientific information and adoption of viable farming techniques by key users. In this regards, he worked as consultant for FAO, WorldFish Center and many other international development agencies. Dr Poumogne has over 20 years of professional and academic experience in research and teaching. His interests and experience include rural small-scale fish farming, partnership with farmers, reservoir fisheries management and environmental impact assessment.

PROUZET, Patrick – As head of a National Research Programme for IFREMER, on “Ecosystem Approach for Fishery Management” Dr Prouzet coordinates scientific projects with the objective of developing a multidisciplinary approach combining biology, economy, fishing technology and fish product transformation in the framework

of the sustainable development. Since the seventies, he has been involved in scientific programmes on amphihaline species, including migratory salmonids, shads, sea lampreys and eel. He is an active member of the International Council for the Exploration of High Seas (ICES) Working Group on European eel and coordinate studies in the framework of an InterregIII programme entitled "INDICANG", the objective of which is to set up a net of knowledge on eel stocks. He worked from 1989 to 2000 on the anchovy population of the Bay of Biscay, coordinating EU projects and provided expert advice to the French fisheries administration and EU (STECF and ICES).

RAHMAN, Mokhlesur – Mr Rahman is a specialist in natural resource management in Bangladesh, with focus on wetlands and coastal zones and livelihood analysis and development. In 1994 he joined the national Center for Natural Resource Studies (CNRS) working, among other things, on wetland and coastal communities' livelihood. Prior to this Mr Rahman was involved in GIS activities and contributed to the development of an aquaculture Environmental Impact Assessment (EIA) manual. He conducted a series of spacial studies on biodiversity of fisheries and carried out a nation-wide (Bangladesh) water-body inventory and developed related databases and GIS maps. From 1990 to 1991 he worked on an FAO field project as an Integrated Fish Culture Expert. Mr Rahman obtained his Bachelor of Science (BSc) and his Master of Science (MSc) degrees from Dhaka University in Zoology and Fisheries. He is a member of the US-based International Association for the Study of Common Property.

SADOVY de MITCHESON, Yvonne – Dr Yvonne Sadovy de Mitcheson is a professor in the Department of Ecology and Biodiversity, University of Hong Kong, which she joined in 1993. Prior to this position, she was Director of the Fisheries Research Laboratory of the Government of Puerto Rico and worked as a fisheries biologist for the Caribbean Fishery Management Council where she also held a position on the Scientific Advisory Committee during the 1990s. She holds a PhD in Zoology from the University of Manchester (1986) and is also the Chair (since 1998) of The World Conservation Union (IUCN) Specialist Group for Groupers and Wrasses (Serranidae and Labridae). Dr Sadovy has published two books and has over 100 other outputs, most of which are peer-reviewed and in international journals. Her speciality is in reef fishes, especially their reproductive biology, and age and growth, and in the conservation and management of vulnerable reef fishes. She has worked extensively in the field in the tropics and has broad in-water and laboratory experience. Dr Sadovy is on the Editorial Boards of Journal of Fish Biology, Conservation Biology, Fish and Fisheries, and Reviews in Fish Biology and Fisheries.

SALEH, Magdy – Dr Saleh is in-charge of supervising five general directorates responsible for the extension and management of aquaculture and inland water fisheries in both the private and governmental sectors. This covers governmental as well as private fish farms, hatcheries, marine wild fry collection/nursery stations, fish disease prevention and fish feed production and formulation. For the last 35 years Dr Saleh has been involved in supporting the development of modern and sustainable aquaculture in Egypt through his continuous work in various national organizations in-charge of fisheries management and development in the country. Dr Saleh obtained his MSc in Aquaculture and Fisheries Management from Stirling University (United Kingdom) (1986) and his PhD in Aquaculture Management and Fish Disease from Suez Canal University, Egypt (1995).

SHELLEY, Colin – Dr Shelley has over 25 years experience in a wide range of marine sciences including aquaculture, fisheries science, environmental science, and marine

biology. He has acted as principal scientist for numerous aquaculture R&D projects in tropical Australia. He is also the manager of aquaculture industry development and policy for the Department of Primary Industries and Fisheries, Queensland. His work includes industry development planning, aquaculture planning, policy development and the regulatory framework for aquaculture. He is actively involved in the commercial development of mud crab aquaculture in the Pacific and Southeast Asia regions. Dr Shelley obtained his MSc in Biology at the University of Papua New Guinea (1982) and his PhD in Zoology from James Cook University (Australia) (1990).

TUPPER, Mark – Dr Tupper is a marine ecologist with 15 years professional and academic experience in research, teaching and consulting. His interests and experience include marine protected area management, habitat ecology, reef fish ecology, fisheries ecology and management, mariculture/stock enhancement, and environmental impact assessment. His present position as Coral Reef Scientist at the WorldFish Center engages him in original research in the field of coral reef resource management and reef fisheries biology. In Micronesia, Southeast Asia and in other parts of the world he has worked on grouper fisheries and aquaculture and enhancement programmes. Dr Tupper obtained his MSc in Biological Oceanography from McGill University (Canada) (1989) and his PhD in Marine Biology from Dalhousie University (Canada) (1994).

Annex 4 – Experts group photograph



Standing (left to right):

Alessandro Lovatelli, Paul F. Holthus, Patrick Prouzet, Robert S. Pomeroy, Mhd Mokhlesur Rahman, Colin Shelley, Don Griffiths, Mark H. Tupper, Kjell Ø. Midling, Magdy Saleh

Seated (left to right):

Makoto Nakada, Øystein Hermansen, Simon Funge-Smith, Francesca Ottolenghi, Yvonne Sadovy de Mitcheson, Choi Kwang Sik, Pham Anh Tuan, Victor Pouomogne

Missing:

Anders F. Poulsen

Capture-based aquaculture (CBA) makes use of wild fish and fishery resources in its production systems. Focusing on this subject, and within the framework of the project “Towards sustainable aquaculture: selected issues and guidelines” implemented by the Food and Agriculture Organization of the United Nations, this document addresses selected key issues of sustainability in relation to current global aquaculture practices and developments. It includes two review papers on the use of wild resources, one covering social and economic aspects and the other on environmental and biodiversity issues, as well as ten papers on selected marine and freshwater species used in CBA.

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