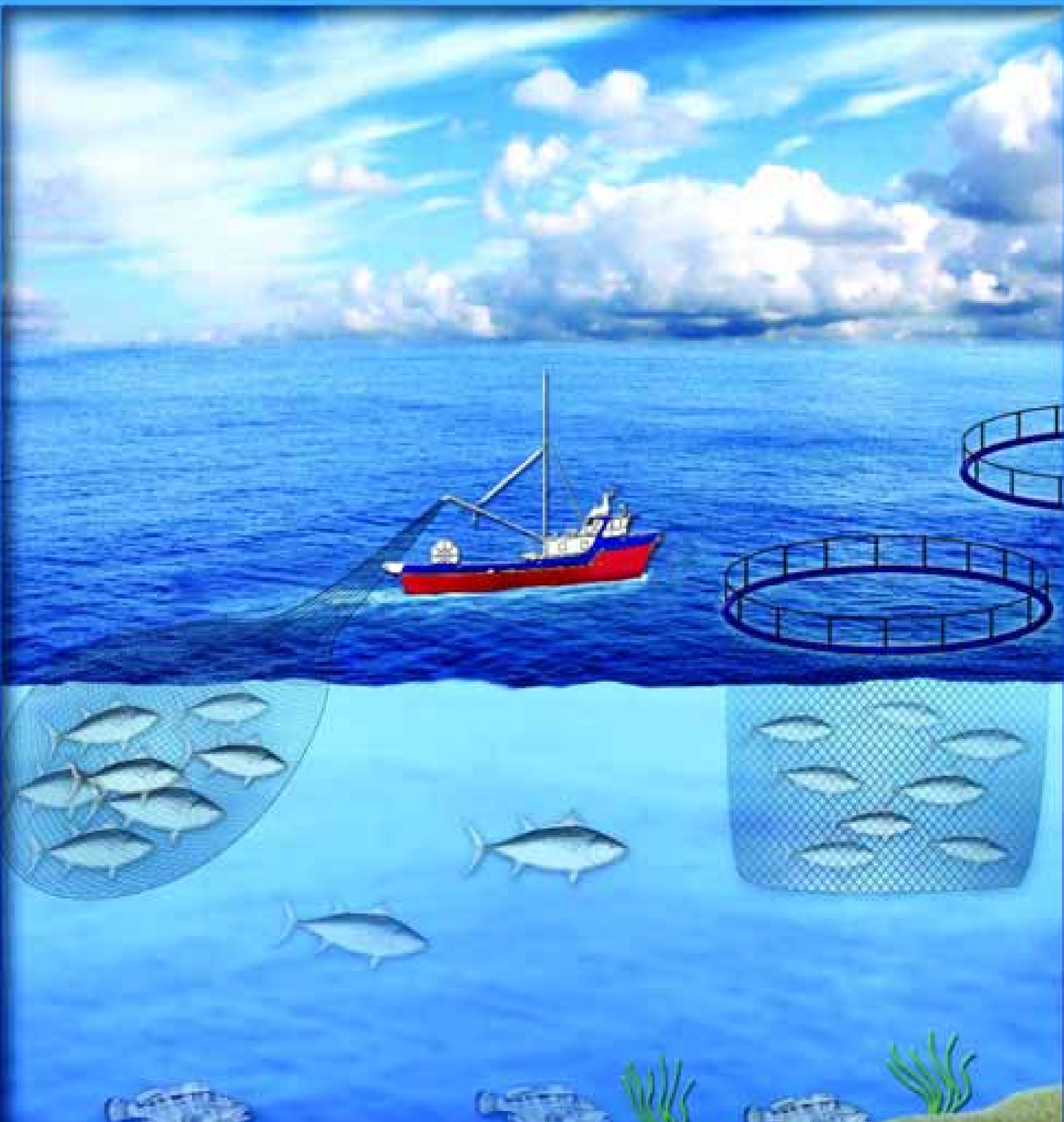
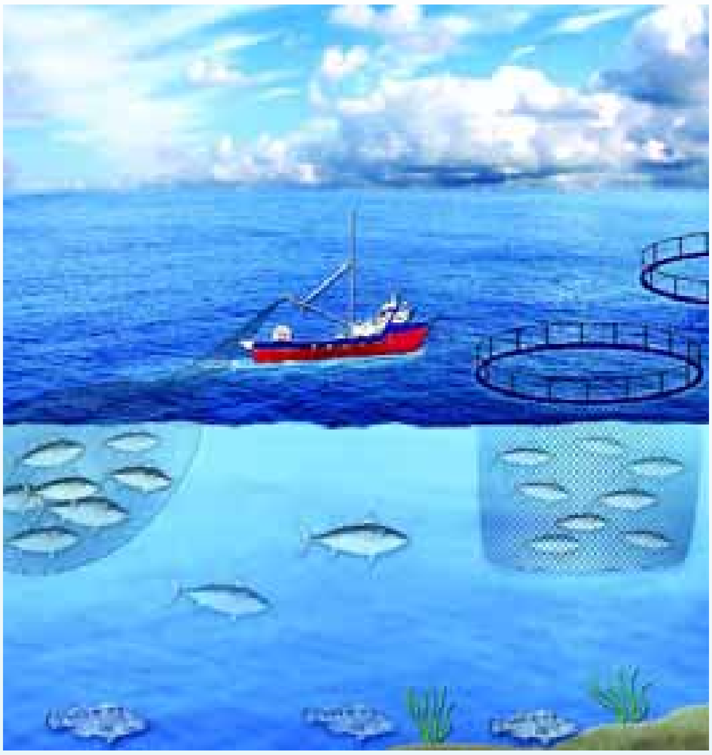
CAPTURE-BASED AQUACULTURE



Cover graphic conceived and designed by:
José Luis Castilla Civit and Alessandro Lovatelli

CAPTURE-BASED AQUACULTURE

THE FATTENING OF EELS, GROUPERS, TUNAS AND YELLOWTAILS



Francesca Ottolenghi, Cecilia Silvestri, Paola Giordano, Alessandro Lovatelli and Michael B. New

Food and Agriculture Organization of the United Nations
Rome 2004

Preparation of this document

This report was prepared for the Food and Agriculture Organization of the United Nations (FAO) by consultants and staff employed by the FAO Fisheries Department to provide a definition and review of the capture-based aquaculture of four species groups: eels, groupers, tunas and yellowtails.

The principal targeted audience includes policy-makers, administrators and trainers in the fields of aquaculture, fisheries and the environment.

It is hoped that the document will provide background information and reference sources for those embarking on research in this field.

This document was prepared with financial assistance from the Government of Japan under the International Conservation and Management of Fisheries Resources Trust Fund Project (GCP/INT/715/JPN).

Abstract

CAPTURE-BASED AQUACULTURE defines and reviews certain practices that are shared between aquaculture and capture fisheries. It specifically considers the on-growing or fattening of four species groups – eels, groupers, tunas and yellowtails – which is based on the use of wild-caught “seed”. The report begins with an introduction on the overlap between aquaculture and fisheries and their global trends. Chapters on the four species groups follow and include information on species identification, fishery trends, the supply and transfer of “seed” for stocking purposes, aquaculture trends, culture systems, feeds and feeding regimes, fish health, harvesting and marketing. Further chapters examine the environmental and socio-economic impacts of capture-based aquaculture, together with the relevant fisheries and aquaculture management issues. Finally, the report looks at food safety issues, as well as identifies topics for future consideration.

Ottolenghi, F.; Silvestri, C.; Giordano, P.; Lovatelli, A.; New, M.B.

Capture-based aquaculture. The fattening of eels, groupers, tunas and yellowtails.

Rome, FAO. 2004. 308p.

Preface

In the past, capture fisheries and aquaculture have tended to be treated as distinct and isolated sectors. However, commonalities in processing and marketing, together with shared environmental and socio-economic concerns and, in some cases, common resources make it important to establish a clear link, especially when an overlap between the two activities exists. One of the most obvious cases of overlap occurs in “semi-aquaculture practices” where the life cycle of an on-grown species cannot be managed on a commercial scale and where the “seed” materials (i.e. larvae, juveniles, adults) are collected from the wild.

Until now, these “semi-aquaculture practices” have not been precisely defined. Commonly, words such as “farming”, “cage farming”, “pen farming”, “ranching” and “fattening” have been loosely used, depending on the size, species and time-scale of the on-growing culture practice. A new definition needs to be adopted in order to avoid confusion and to enable the issues related to such farming practices to be identified more easily.

The aim of this report is to define and review this “semi-aquaculture practice”, which has been more accurately named “capture-based aquaculture”.

Acknowledgements

The authors wish to record their gratitude to the many people that assisted in the preparation of this document, who included Roberto Agonigi (Nutreco Holding N.V., Italy), Felipe Aguado Jiminez (Regional Center of San Pedro del Panatur, Spain), Fabio Badalamenti (National Research Council, Laboratory of Marine Biology, Italy), Uwe Barg (Fisheries Department, FAO), Mark Scicluna Bartoli (European Commission, Belgium), Johann Bell (WorldFish Center, Malaysia), Daniel D. Benetti (University of Miami, USA), Antonio Bernal Bas (Tuna Graso, Spain), Francesco Bertolino (Egadi Marine Protected Area, Italy), Arnaud Bertrand (Research Institute for Development, Chile), Isidra Bombeo-Tuburan (Southeast Asian Fisheries Development Center, Philippines), Alain Bonzon (Fisheries Department, FAO), Christopher R. Bridges (University of Heinrich-Heine, Germany), Richard Brill (National Marine Fisheries Service, USA), Chris Carter (University of Tasmania, Australia), Steven Clarke (South Australia Research and Development Institute, Australia), John Corbin (Hawaii State Aquaculture Development Program, USA), Denis Coves (IFREMER, France), Juana Delgado (Ministry of Agriculture and Fisheries, Spain), Wim van Eijk (Dutch Association of Fish Farmers, Netherlands), Andreina Farrugia (University of Malta, Malta), Stefano Fazi (Water Research Institute, Italy), Jean-Marc Fromenin (IFREMER, France), Antonio García Gómez (Oceanographic Institute of Spain, Spain), Maurizio Ginocchi (APCOM, Italy), Cyrille Guernalec (CNPMEM Bluefin Tuna Commission, France), Cathy Hair (WorldFish Center, Malaysia), Brian Jeffriess (Tuna Boat Owners Association of South Australia, Australia) Don Jellyman (National Institute of Water and Atmosphere, New Zealand), Robert E. Johannes (R.E. Johannes Pty. Ltd, Australia), Saadet Karakulak (University of Istanbul, Turkey), Ivan Katavic (Ministry of Agriculture and Forestry, Croatia), Mark Lokman (University of Otago, New Zealand), Hector Lupin (Fisheries Department, FAO), Molly Lutcavage (New England Aquarium, USA), Masashi Maita (Tokyo University of Fisheries, Japan), Jacek Majkowski (Fisheries Department, FAO), Tom Mallows (English Nature, UK), Natalia Martini (Oxford University, UK), Fabio Massa (Fisheries Department, FAO), Naozumi Miyabe (National Research Institute of Far Seas Fisheries, Japan), Peter M. Miyake (International Commission for the Conservation of Atlantic Tunas, Spain), Peter Montague (Aquafin CRC, Australia), Gabriel Mourente Cano (University of Cadiz, Spain), Constantinos Mylonas (Institute of Marine Biology of Crete, Greece), Makoto Nakada (Nisshin Feed Co. Ltd., Japan), Isik Oray (University of Istanbul, Turkey), Ayaka Amaha Ozturk (University of Istanbul, Turkey), Philippe Paquotte (OFIMER, France), Luz Perez Igualada (Polytechnical University of Valencia, Spain), Mike Rimmer (Department of Primary Industry, Australia), Sean Tibbetts (Nova Scotia Agricultural College, Canada), Yvonne Sadovy (University of Hong Kong, China), Robert Sluka (University of Miami, USA), Rohana Subasinghe (Fisheries Department, FAO), Kandula Sujatha (Andhra University, India), Sergi Tudela (WorldWide Fund, Spain), Mark H. Tupper (University of Guam, USA), Filip Volckaert (Catholic University of Leuven, Belgium), Rolf Willmann (Fisheries Department, FAO), K. Yamoaka (Laboratory of Aquatic Biology, Japan) and Peric Zarko (Ministry of Agriculture and Fisheries, Malta). The authors are also indebted to José Luis Castilla Civit, who was responsible for its final layout.

CONTENTS

List of tables

List of figures

Executive summary

Capture-based aquaculture is a global activity but has specific characteristics that depend on geographical location and the species being cultured. The species groups used in capture-based aquaculture include molluscs (e.g. oysters, mussels, scallops), crustaceans (e.g. shrimps, crabs) and finfish (e.g. eels, grey mullets, milkfish, yellowtails, groupers, rabbitfish, tunas). The scale of such practices is difficult to quantify, but it is estimated that about 20 per cent of aquaculture production comes from capture-based aquaculture. The total value of the farmed production of the four species groups considered in this report (the figures reported to FAO are believed to be underestimates) in 2000 alone exceeded US$ 1.7 billion.

This report focuses on four species that show high market demand and value and have a short grow-out time to market size – eels, yellowtails, groupers and tunas. A description of the rearing, harvesting and marketing practices for each species is provided, together with a review of environmental, social, economic, food safety and management issues. The following are the major findings:

- **Seed supply:** no suitable commercial supply of "seed" (larvae, juveniles) exists for any of the four species groups. The use of wild-caught seed for their capture-based aquaculture potentially affects their capture fisheries but any damage caused has neither been fully defined or understood nor quantified.
- **Eels:** eel culture benefits from well-developed artificial feed supplies, has low environmental impacts, and requires limited land. The main constraint to the expansion of this sector is seed supply, which can only be solved by hatchery production.
- **Groupers:** the further expansion of grouper rearing will depend primarily on market development. However, better seed catching and culture techniques to reduce wastage, the development of commercially acceptable artificial feeds to replace "trash fish", better control of diseases, and a transfer of culture activities away from polluted areas are also necessary.
- **Tunas:** further expansion of tuna fattening is anticipated in the short-term. However, long-term sustainability depends on increasing the supply of seed, currently constrained by tuna quotas and the lack of economically sound methods of hatchery production; improvements in artificial feed formulation to reduce baitfish consumption, improve FCRs and ensure meat quality; expanding markets beyond the Japanese market; and improvements in offshore technology and harvesting systems. Environmental and ethical concerns affect the public image of tuna rearing but control over the complete life cycle would remove ecological concerns and help to ensure a sustainable future.
- **Yellowtails:** hatchery-reared yellowtail juveniles are of poorer quality than those that are wild-caught, so seed supply remains a constraint. Considerable interest in expanding this form of aquaculture not only exists in Japan, where the traditionally cultured Japanese amberjack is being joined by the rearing of two other species (yellowtail amberjack and greater amberjack), but also elsewhere, notably in Australia and the Mediterranean. Besides solving the problem of seed supply, improved feeds and feeding practices and the introduction of better management to limit losses from "red tide" events are needed. Expanding the range of products available would also be advantageous.
- **Environmental impact:** there is a strong need for better data on the biology and fisheries of the species included in this report, with a view to determining Maximum Sustainable Yield (MSY) and ensuring sustainability. Seed capture for aquaculture has a potentially negative (but, as yet unquantified) impact that adds to existing high levels of fishing effort, increasing vulnerability to extinction. In addition, other topics causing environmental impact require further study. These include improved site selection; the development of feeds that cause less pollution and are less reliant on limited sources of marine protein and oil; the amelioration of the habitat destruction that is caused by certain types of seed capture; improvements in feeding practices; and better monitoring and control of existing farms.
- **Social and economic impacts:** capture-based aquaculture provides significant positive returns in areas with depressed and marginal economies, and an alternative livelihood for coastal communities. However, the difficulties of marketing fresh fish and supplying markets that demand

live fish (e.g. groupers), and the need to expand markets limit its potential. The development of new, value-added products would alleviate this problem. Increased competition caused by production expansion (e.g. of yellowtail culture) may lead to falling prices, as has occurred with other farmed species. Unique selling positions (USP) need to be identified for the products from capture-based aquaculture. Skill gaps are evident in the sector, including specific knowledge on economics and management, the suitability of individual (new) species for culture, information on their biology and dietary requirements, and marketing. Capture-based aquaculture is labour intensive in its farming and processing operations, and can contribute to poverty alleviation in developing countries.

- **Management of resources and culture practices:** many difficulties are posed by the interactions between capture-based aquaculture and fisheries. Specific rules that complement existing regulations to improve management practices are required. Innovative technologies and concepts are needed to solve the problems of overfishing, bycatch, and environmental impact (e.g. on seed catching areas for groupers). Considerable efforts are being made to identify adequate responses to the challenges created by capture-based aquaculture, in particular by the General Fisheries Commission for the Mediterranean (GFCM) and the International Commission for the Conservation of Atlantic Tunas (ICCAT) in the Mediterranean. Capture-based aquaculture not only needs recognition as a distinct sector but integration into resource use and development planning. The principles set out in the FAO Code of Conduct for Responsible Fisheries (CCRF) would provide useful guidance towards identifying factors that inhibit sound management and development; consultation with all stakeholders, including the private sector, is essential in this process.
- **Food safety issues:** in common with other types of aquaculture, careful choice of aquafeed ingredients and on-growing sites, in addition to good management practices, are necessary to avoid the accumulation of chemical and antibiotic residues, in order to ensure the continued safety of farmed products. Capture-based aquaculture provides other opportunities to reduce the risks associated with food safety. For example, where ciguatera is a problem, capture-based products might be labelled as "ciguatera-free". Certification systems would be advantageous for capture-based aquaculture products.
- **Statistical issues:** specific statistical problems exist where the animals stocked for on-growing are already of significant size. Of the four species groups considered in this report, this problem applies only to bluefin tuna fattening; however it also applies to other species where large wild-caught seed are (or may in the future be) stocked in capture-based aquaculture. The difficulty of separating the early (fisheries) production from late (aquaculture) production of tunas is a topic of intense discussion within GFCM and ICCAT. Practical difficulties (e.g. multiple handling of live fish to measure weight) exacerbate the statistical problems.
- **The future:** capture-based aquaculture is an economic activity that is likely to continue to expand in the short term, both for those finfish species currently under exploitation and possibly with others that may be selected for aquaculture in the future. However, in the long term, the capture-based aquaculture of certain species of finfish may have to cease, through legislation, if it is viewed as a threat to their fisheries, to natural recruitment in the wild, and perhaps to their very existence. This is why it is critically important that means be found to rear these species throughout their full life-cycle that are economically viable. When that goal is achieved, not only will the future aquaculture production of those species be assured but restocking programmes may be feasible to enhance their capture fisheries. While there are opportunities for market expansion for all of the species discussed in this report, there is a proven tendency (e.g. salmon, seabass, seabream) for farm-gate prices to decline as supply increases. Thus expansion will only be feasible if farmers are able to reduce costs. From a technical point of view the main constraint to expansion is seed supply.
- **In conclusion:** the development of seed production in hatcheries on an economically viable commercial scale, and the refinement of grow-out technology to ensure that the fattening phase is environmentally acceptable are the critical issues for the future. Failure to address these matters successfully would have severe consequences for both aquaculture and capture fisheries.

chapter 1

THE AQUACULTURE-FISHERIES OVERLAP: CAPTURE-BASED AQUACULTURE

1

THE AQUACULTURE-FISHERIES OVERLAP: CAPTURE-BASED AQUACULTURE

Introduction

Fishing and aquaculture are often viewed as separate activities but we now need to ask the question "where does fishing end, and aquaculture start?" The release of hatchery-reared animals into the wild for capture fisheries enhancement is aquaculture-driven and is therefore referred to as "culture-based fisheries" (FAO 1997b). Another type of activity entails the capture of animals from the wild for farming purposes. We have coined the term "capture-based aquaculture" to cover this form of overlap between fisheries and aquaculture, namely when fishing is put at the service of aquaculture. This report is concerned with capture-based aquaculture.

Definitions

The word "aquaculture" is defined by the Food and Agriculture Organization of the United Nations (FAO) as follows:

> "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 rearing period contribute to aquaculture" (FAO 1997b).

Current aquaculture technology allows the commercial and viable production of a number of organisms through the management of their entire life cycles. The "seed" materials (larvae and juveniles) are produced under controlled conditions, starting from the maturation of broodstock, which eliminates the need for the collection of juveniles from the wild.

Closed life-cycle aquaculture involves a thorough understanding of the behaviour, habitat and environmental requirements, reproductive biology, nutritional requirements, and larval and juvenile physiology of each species, as well as its susceptibility to disease under culture conditions. Moreover, it involves the development of all aspects of fish husbandry, such as the facilities required for the various life-cycles stages (broodstock holding tanks/sea cages, nursery tanks/cages, grow-out facilities), feed development, fish handling systems, and disease control. Such procedures and techniques have been developed for several diadromous and marine fish species – notably salmonids, seabass, seabream, and more recently for cod.

Another definition of aquaculture was derived by Beveridge (1996):

> "Aquaculture, or the farming of aquatic organisms, is achieved through the manipulation of an organism's life cycle and control of the environmental variables that influence it. Three main factors are involved: control of reproduction; control of growth; and elimination of natural mortality agents. Control of reproduction is an essential step, otherwise farmers must rely on naturally spawning stocks. The supply of fry from the wild may be restricted to a particular season and a particular area, and there may also be shortages due to over-exploitation of wild stocks".

Many species that are commercially important cannot currently be spawned in captivity. For others, the complete life cycle has only been completed at the research and development level, which means that insufficient "seed" material is available for commercial farming operations. Where controlled breeding techniques have not been perfected, farmers have to depend on "seed" available from the wild. In these types of aquaculture practices there is a need to collect "seed" fish directly from the wild, ranging from larvae, small to medium-sized juveniles, or even large individuals.

These "semi-aquaculture practices" have not previously been defined exactly: the terms that are currently used include farming, caging, penning, and fattening, depending on the size, species, and the timescale of the culture practice, i.e. the activities that are related to the on-growing of the fish. When the rearing of tunas caught from the wild is discussed, their culture is denominated in various ways, depending on whether the on-growing/fattening activity is being referred to by working groups, or by those involved in marine aquaculture (mariculture) or fisheries. These differences in terminology have been observed in documents from FAO, the General Fisheries Commission for the Mediterranean (GFCM), and the International Commission for the Conservation of Atlantic Tunas (ICCAT). In the Mediterranean, current practices could be described as "tuna farming" and "tuna fattening". The first, carried out mostly in Croatia, is where the overall weight of small fish is increased substantially through culture periods ranging from 1 to 3 years. In the latter case, larger fish are kept in cages for a shorter period to increase their fat content, a factor which allows them to be sold for a better price in commercial markets, especially in Japan.

The fundamental difference between the use of the terms "aquaculture" and "farming" by Beveridge (1996) and FAO (1997b) is that the former applies these terms only to practices where the reproduction of the organism is controlled, while the FAO definition is more general: "...some sort of intervention in the rearing process to enhance production...". Inability to complete the life-cycle in captivity does not bar the farming activity from being considered as aquaculture under the FAO definition.

A more holistic approach is needed, one that acknowledges the links between aquaculture and fisheries. According to Williams (1996): "for too long fisheries and aquaculture have been treated as sectors in isolation, a practice that has ignored important linkages and externalities". The release of hatchery-reared animals into the wild for capture fisheries enhancement, being aquaculture-driven, is referred to as "culture-based fisheries" (FAO 1997b). However, there is a need for a better understanding of "semi-aquaculture practices" where the farming activity is based on the stocking of wild-caught animals. For this report, it has been necessary to derive and adopt a new term, in order to avoid confusion and to identify the issues related to such farming practices easily. This term is "capture-based aquaculture". This term represents an overlap between fisheries and aquaculture and is defined as follows:

Capture-based aquaculture is the practice of collecting "seed" material – from early life stages to adults - from the wild, and its subsequent on-growing in captivity to marketable size, using aquaculture techniques.

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.

Background

The role of aquaculture in providing food, employment and foreign exchange income – often as a complementary alternative to the outputs from the capture fishery sector or as a supplementary economic activity – is ever increasing. Currently the fastest growing food production sector in the world, aquaculture production has increased at an average compound rate of 9.2 percent since 1970, compared with only 1.4 percent for capture fisheries and 2.8 percent for terrestrial farmed meat production systems (FAO 2002c). In 2000, the global aquaculture production of foodfish (fish, crustaceans and molluscs) totalled nearly 36 million tonnes, plus another 10 million tonnes of aquatic plants (FAO 2002a). The total annual value of foodfish produced by aquaculture had reached nearly US$ 51 billion by 2000. Most of the global aquaculture output is located in developing countries, significantly in low-income, food-deficit countries (LIFDCs), with China by far the dominant country. In 2000, over 38 million tonnes (including plants) was produced in LIFDCs. Expansion has been rapid; global production of foodfish through aquaculture increased by a factor of 2.5 between 1991 and 2000 (FAO 2002a). Providing aquaculture production remains responsible, it has the potential to supply increasing yields without reducing the production from wild stocks.

Aquaculture can be viewed as a potential means of relieving pressure on fish stocks, as well as a means of filling the increasing supply-demand gap for marine fishes (Williams 1996). With the yields from many capture fisheries now fixed at their maximum, and with the increasing demand for fish and fishery products, expectations for aquaculture to increase its contribution to the world's production of aquatic food are very high. There is also hope that aquaculture will continue to strengthen its role in contributing to food security and poverty alleviation in many developing countries (FAO 1997b). The Code of Conduct for Responsible Fisheries (CCRF) stresses: "States should consider aquaculture, including culture based fisheries, as a means to promote the diversification of income and diet. In so doing, States should ensure that resources are used responsibly and adverse impacts on the environment and local communities are minimized" (FAO 1995).

The actual effects of aquaculture, including wild seed capture on global capture fisheries in general, has only recently received serious attention (Naylor *et al.* 2000). The potential impacts of the removal of juveniles from the wild for capture-based aquaculture on stocks (and whether or not production is actually enhanced through this kind of mariculture practice), are rarely considered. A critical problem is whether mariculture practices based on the capture of juveniles from the wild are sustainable, or could be modified to become so (Sadovy and Pet 1998). The focus of research and understanding should be: the biology of the species; the fisheries for the juveniles; and the potential impacts on remaining wild stocks that are or could be caught for grow-out systems (Johannes 1999).

The capture-based aquaculture industry is going through a transitional phase: it is at a critical crossroads between research and development, and both public and private sectors will need to continue to evaluate trends as the sector develops.

The scientific and technical aspects of capture-based aquaculture are firmly established, and they constitute the necessary basis for its economic development. However, after 30 years of research and development (and many millions of US dollars invested) there are still no economically viable mass-scale technologies to reproduce bluefin tuna in captivity, although recent claims from Japan suggest that this is now possible (www.intrafish.com). This time span is similar to that needed to obtain penaeids in Japan, salmon in Norway, and seabream and seabass in the Mediterranean; hatchery technology for these species now exists. With continuing high market demand and prices, it is likely that the sector will succeed in developing economically viable means of sustaining the practice. It is important, as for the other species, to take into account several ecological parameters that are still poorly investigated or unknown, and to invest rationally in experimental and research activities that could improve and achieve a total control of a species life cycle (Doumenge 1999).

Capture-based aquaculture is a worldwide aquaculture practice and has specific and peculiar characteristics for culture, depending on areas and species. An overview (Badalamenti *et al.* 1998; Ciccotti, Busilacchi and Cataudella 1999; Doumenge 1999; Tucker 1999; Garcìa 2000; Nakada 2000; Sadovy 2000; EIFAC/ICES 2001; Tibbetts 2001; Clarke 2002; Hair, Bell and Doherty 2002; Katavic, Vicina and Franicevic 2003a) shows a worldwide distribution of this practice. Some examples of the species/groups harvested as wild juveniles and the various countries/regions where capture-based aquaculture is practized is presented below:

- shrimp (*Penaeidae*) in South America and South-East Asia;
- milkfish (*Chanos chanos*) in the Philippines, Sri Lanka, Pacific Islands and Indonesia;
- eels (*Anguilla* spp.) in Asia, Europe, Australia and North America, mainly in China, Japan, Taiwan Province of China, The Netherlands, Denmark and Italy;
- yellowtails (*Seriola* spp.), mainly in Japan, Taiwan Province of China, Viet Nam, Hong Kong, Italy, Spain, Australia and New Zealand;
- tunas (*Thunnus* spp.) in Australia, Japan, Canada, Spain, Mexico, Croatia, Italy, Malta, Morocco and Turkey; and
- groupers (*Epinephelus* spp.), which is now widespread in Indonesia, Malaysia, Philippines, Taiwan Province of China, Thailand, Hong Kong, People's Republic of China, and Viet Nam, and in other parts of the tropics, for example in southeastern USA and Caribbean. Grouper culture is also on-going in India, Sri Lanka, Saudi Arabia, Republic of Korea and Australia.

These species are caught and farmed using various techniques and systems, depending on different local cultural, economic and ethnical traditions. The cultural and ethnical heterogeneity, as well as the economic differences, are partly reflected in the organization of the fishing sector. In some areas this is typically artisanal, rather than industrial in nature. The collection methods of grouper "seed" for capture-based aquaculture systems are local and artisanal, e.g. *gangos* (Philippines) and *temarang* (Malaysia), offering an important source of employment and income to the poorest segment of the coastal population. Fishing for juvenile reef fish requires an extremely low capital investment (US$ 27 per family in the Philippines) (Johannes 1997). At the other end of the scale, bluefin tuna fisheries in the Mediterranean are wholly industrialized enterprises, which need heavy capital investment: a purse seine boat can cost up to US$ 500 000, and helicopters are often used to locate shoals.

Most fishing fleets have adapted to technological progress and are using larger, more powerful boats, incorporating sophisticated electronic fish finding equipment, and advanced catching systems. These developments have fundamentally altered the dynamics of the sector, widening the "gap" between artisanal and industrial fisheries.

Capture-based aquaculture could be considered as an unsustainable aquaculture practice, due to the increasing pressure on fish stocks, and one that could cause successive stock depletion; low recruitment; stock collapse; reductions in genetic biodiversity; and subsequent impact on the ecological dynamics and processes in the wider aquatic environment. Capture-based aquaculture could pose a threat, not only to wild stocks, but also to the industry's own long-term potential.

However, Hair, Bell and Doherty (2002), believe that there is a need to highlight the importance and potential of this type of aquaculture. With recent advances in the knowledge of larval biology and aquacultural engineering, there is a tendency to assume that further development of aquaculture will be focused on the mass production of juveniles in hatcheries. While the use of hatchery technology may be the only way to produce sufficient numbers of juveniles for stocking or increasing their supply beyond current levels for many species, much of the world's coastal aquaculture production can still be expected to come from the supply and availability of capture-based juveniles.

A particularly attractive feature of aquaculture based on captured juveniles is that many of the environmental concerns associated with the grow-out of juveniles produced in hatcheries (e.g. the transfer of diseases and the "genetic pollution" of wild stocks), is not inherent to the process. The collection of juveniles from the wild, however, does not come without its own set of responsibilities.

The highest priority among these is the need to ensure that the increased production from the culture of juveniles more than offsets any losses in the yield from the wild stock. Capture-based aquaculture is not only based on the catching and removal of juveniles, but can also use mature individuals, e.g. giant individuals for bluefin tuna. In any event, capture should not adversely affect recruitment and the stock level of a wild population, or cause disadvantages to other users of the resource.

Economic considerations are the key drivers for capture-based aquaculture. The selection of species for culture reflects their acceptability and demand in local or international markets. Market requirements are determined primarily by people's tastes and customs. In Japan, domestically caught tunas are considered to be the highest-grade tuna available on the market, because of their excellent colour, freshness and fat content (Ikeda 2003), and the traditional Japanese custom to eat raw fish (*sushi* and *sashimi*). Global bluefin tuna farming has caused an important socio-economic impact in Japan. Farmed bluefin tuna from other sources is much cheaper – 30 to 50 percent less than wild varieties, and the same is true for southern bluefin tuna. The abundance of fattened bluefin tuna from farming centres has opened new markets in recent years (Miyake *et al.* 2003) that have filled the gap between the "top quality" tuna served in the top *sushi* restaurants and the more "popular" ones. Today, bluefin tuna is available throughout the year in the *Kaiten-sushi* type restaurants and even in supermarkets.

As capture-based aquaculture potentially generates higher profits than other aquaculture systems, the market demand for the products and species cultured is high and it is likely that efforts to promote this activity will significantly increase. This development will be capable of causing a number of very important and diverse effects, not all of them beneficial. Capture-based aquaculture, being an overlap between fisheries and aquaculture, combines various characteristics of these two sectors: the necessity for species-specific gears, size selective gears (nets, etc.), stock assessments, fishing effort restrictions and regulations (time and space closure), and bycatch, etc., from the fisheries; and the culture system (cages, ponds, etc.), environmental impacts, fish diseases, and the use of pharmaceuticals, etc., from aquaculture.

Other aspects are specific to capture-based aquaculture practices. For example, capture-based aquaculture requires the movement of live fish from the place of capture to the on-growing area. This can lead to the loss or distortion of catch data, which appears to be happening in the bluefin tuna fishery of the Mediterranean. There is an urgent need to develop new regulations or other legislation to control these activities, e.g. catching methods; seasons; sizes; quantity; catch per unit effort; import-export of capture-based juveniles; etc.

Thus it can be stated that an immediate consequence of capture-based aquaculture is that it complicates the evaluation of target stock assessment, which forms the basis for designing a rational national and regional fisheries management system. These procedures become more difficult when capture-based farmed species are widely distributed or migratory. Exploitation of the same resources by fleets from different countries reinforces the need for a shared strategy to ensure the Maximum Sustainable Yield (MSY) of the resource. International cooperation is essential, given the difficulties in developing a common policy which safeguards the stock, and the incomes of politically and economically heterogeneous countries.

To develop and apply regional models for sustainable capture-based aquaculture it is imperative to obtain information regarding the life history, characteristics, recruitment dynamics, habitat requirements and fishery activities for each species. For example, large groupers are particularly vulnerable to intensive fishing because of their longevity, slow growth, delayed reproduction, and aggregate spawning. The over fishing of adult groupers would result in a decline in the capture-based juveniles available for farming, while the over fishing of juveniles could have a much more lasting impact, not only on the adult fishery, but to the supply of juveniles for farming.

As capture-based aquaculture is a practice which is constantly developing, countries should create or amend the comprehensive regulatory framework to ensure that the sector develops in a sustainable manner; the inadequacy of existing legislation to control the growth of the industry properly constitutes a common problem.

Besides the economic, social, biological, and management aspects mentioned above, there are various technical aspects (which are also common to other farming systems) that are important for consumer health and food safety. It is necessary to stress that these aspects are effectively common to all aquaculture practices, but in capture-based aquaculture their importance is greater owing to the fact that many of its products are consumed raw. The situation is further complicated where non-formulated diets, e.g. trash fish, are used to feed the fish; this may cause deterioration in feed quality when it is not properly stored. This could result in greater risks to the health of the farmed species, and the consequent requirements to treat the fish for ill health. There is a lack of research studies on the prevention of the risks associated with feed consumed by capture-based farmed species. Trash fish has the potential to introduce diseases and infections, and it is therefore necessary to develop certification systems to guarantee quality and good practices for capture-based aquaculture operations.

The long-term sustainability of the industry depends largely on a reduction of its reliance on bait fish for feeding; problems include fluctuations in bait fish quality and its availability (seasonability) (Nakada 2000; Montague 2003). At the moment information on the environmental impact of almost all capture-based aquaculture is still lacking. Reports focus on the impact of salmon, seabream and seabass aquaculture, but little is known about the effect of capture-based farmed species. Enrichment and degradation of the aquatic ecosystems in the vicinity of fish farms is possible where management does not measure and control outputs from the site. Potential wastes from fish farms include metabolic products (faecal and excretory urinary material) and uneaten food, which directly or indirectly enter the aquatic environment. The level of environmental impact depends upon the intensity of fish culture activities, (i.e. stocking density and feed inputs) and the characteristics of the culture site. Capture-based aquaculture systems which use trash fish for feeding have an enhanced potential to pollute the environment than intensive farming operations that use special low-pollution feeds. The level of sustainable production in each area will vary, depending on the level of environmental impact.

There is an increasing interest in monitoring the environmental discharges and degradation of the area caused by fish farming. In many countries, new legislation has set new criteria for environmental quality and introduced tighter controls. Japan introduced new laws in 1999 for monitoring sediment and water quality in fish farming areas, in order to assess its sustainability (Pawar *et al*. 2001). Sustainable development of capture-based aquaculture needs careful site selection, pre-assessment of the carrying capacity of sites using bio-modelling, the use of suitable feeding regimes, good health management, stocking density control, and accurate environmental impact assessments. Sustainable development should ensure the conservation of the marine environment for future generations and as well as bring both short-term and long-term benefits to the industry.

Capture-based aquaculture has the potential to generate high profits when compared to other aquaculture activities. This has naturally resulted in an increase in this system of aquaculture, which is capable of bringing about a number of very important and diverse socio-economic effects. Capture-based aquaculture can cause significant positive social and economic changes at a regional level, particularly in those regions with depressed and marginal local economies, characterized by high rates of unemployment. New employment opportunities are generated and specialists are required for its different activities, e.g. divers, biologists, quality measurements, "seed" collectors, harvesters, etc. Although it can bring high profits for a few users, however, capture-based aquaculture can also lead to negative impacts when it conflicts with other coastal activities, such as navigation, fisheries, tourism and industry.

It is important to realize that negative impacts are not always predictable, as there is little data yet available, some of their characteristics are species-specific, and it is very difficult to have a complete perspective of the entire socio-economic spectrum. Capture-based aquaculture is a complex issue and it is necessary to make a detailed analysis of every aspect which is directly or indirectly associated with it. There is a need for a better understanding of the problems and advantages that may be associated with this practice.

The status of global aquaculture and fisheries

Capture-based aquaculture is receiving particular attention in maritime nations world-wide. The system, though it is an overlap between fishery and aquaculture that exploits the same resources, also has its own specific characteristics. The result is an atypical system that interacts with fisheries and aquaculture. It is thus necessary to assess trends in fisheries and aquaculture, in order to obtain a better overview of the resource status, and to assess the positive and negative interactions that could arise from this aquaculture practice.

Resource exploitation (whether in the activity concerns larval, juvenile or adult stages) must fall in line with responsible and sustainable aquaculture and fishing policies. Responsibilities must be shared by fishermen, farmers, researchers, institutions, and administrations, at national and regional levels, as stated in Code of Conduct for Responsible Fisheries (FAO 1995). Careful use of resources is a fundamentally important aspect of "sustainable development", which is defined as "the management and conservation of natural resources and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations" (FAO 1997b). Policy and decision-makers increasingly have to consider a holistic approach towards fisheries management decisions and aquaculture policy development: this is fundamental to sustainable development in the whole fisheries sector. Global demand for fish is increasing and the enforcement of national and regional legislation to protect dwindling resources is essential.

Landings from the global fisheries were 62.8 million tonnes in 1970 and 67.7 million tonnes in 1980 (FAO 2002a). By 1990, they had risen to 85.5 million tonnes. Since 1994, they have become generally stable at 90-95 million tonnes (FAO 2002b), while the production of foodfish through aquaculture showed an increase for the same period, from 20.8 million tonnes in 1994 to 35.6 million tonnes in 2000 (FAO 2002a). For this reason, many people rely on aquaculture expansion to relieve the pressure on fish stocks and supply increasing consumer demand.

Trends in global fisheries

In 2000, global capture fisheries harvested nearly 95 million tonnes (FAO 2002b) from marine areas and inland waters, with the Asian region contributing approximately 42 percent of total landings, followed by South America with 19 per cent and Europe with 16 percent. Global capture fisheries contributed 72 per cent of the total fishery production of 130 million tonnes.

The Northwest Pacific, with 23 million tonnes, had the largest reported landings from marine fisheries in 2000, followed by the Southeast Pacific and the Northeast Atlantic regions (FAO 2002b). Production in the Northwest Pacific remained almost steady between 1996 and 2000. Total production in the Southeast Pacific increased from 14 million tonnes in 1999 to 16 million tonnes in 2000, but was still much lower than the 20.3 million tonnes recorded in 1994. Production in the Northeast Atlantic remained very stable between 1994 and 2000. In the other marine fishing areas, production has also remained relatively stable since 1994. Figure 1 shows the major sources of global capture fisheries production in 2000, as defined by FAO fisheries area.

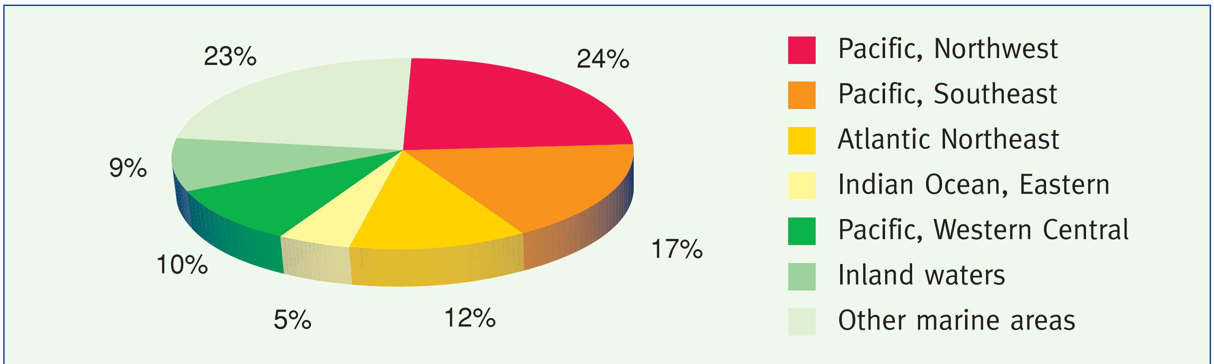


Figure 1. Global fish landings per fishing area in 2000 (FAO 2002b)

In 2000, China was the leading producing country (17.0 million tonnes) followed by Peru (10.7 million tonnes), Japan (5.0 million tonnes), the United States (4.8 million tonnes), Chile (4.3 million tonnes), Indonesia (4.1 million tonnes), the Russian Federation (4.0 million tonnes), India (3.6 million tonnes), Thailand (2.9 million tonnes) and Norway (2.7 million tonnes). These ten countries accounted for 63 percent of the entire 2000 capture fisheries production by volume (Figure 2).

Figure 3 shows the general trend in global capture fisheries landings from 1991 to 2000 (Table 1). From 1991 to 2000 the average growth rate for capture fisheries production was very small (1.3%). Most of this was due to increases in production from inland waters (3.9%); average annual expansion in marine areas was much smaller (1.1%).

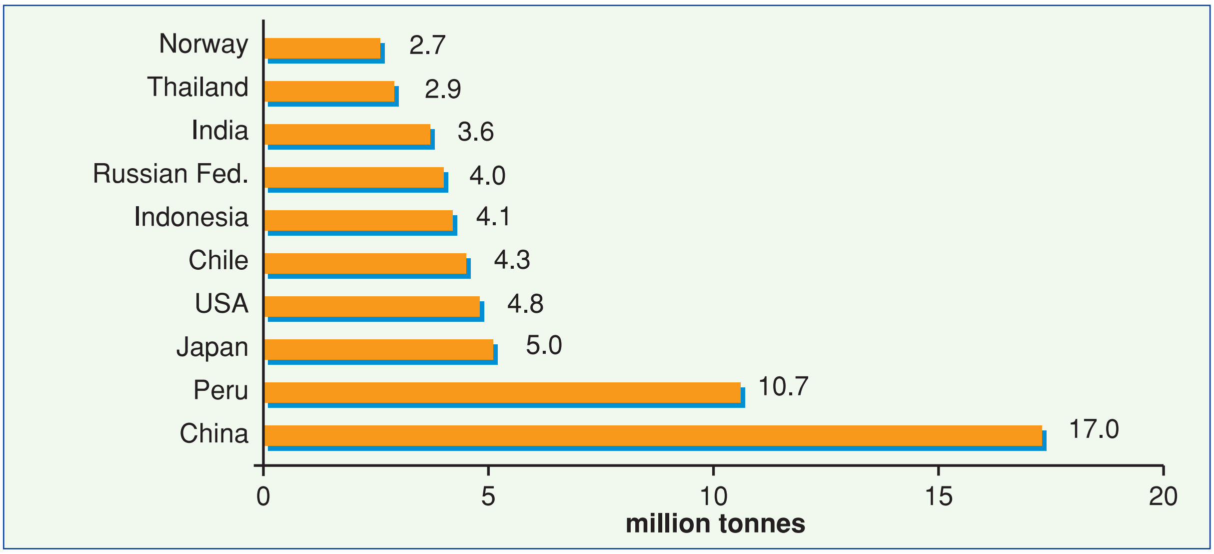


Figure 2. Fish landings from the top ten fishing nations in 2000 (FAO 2002b)

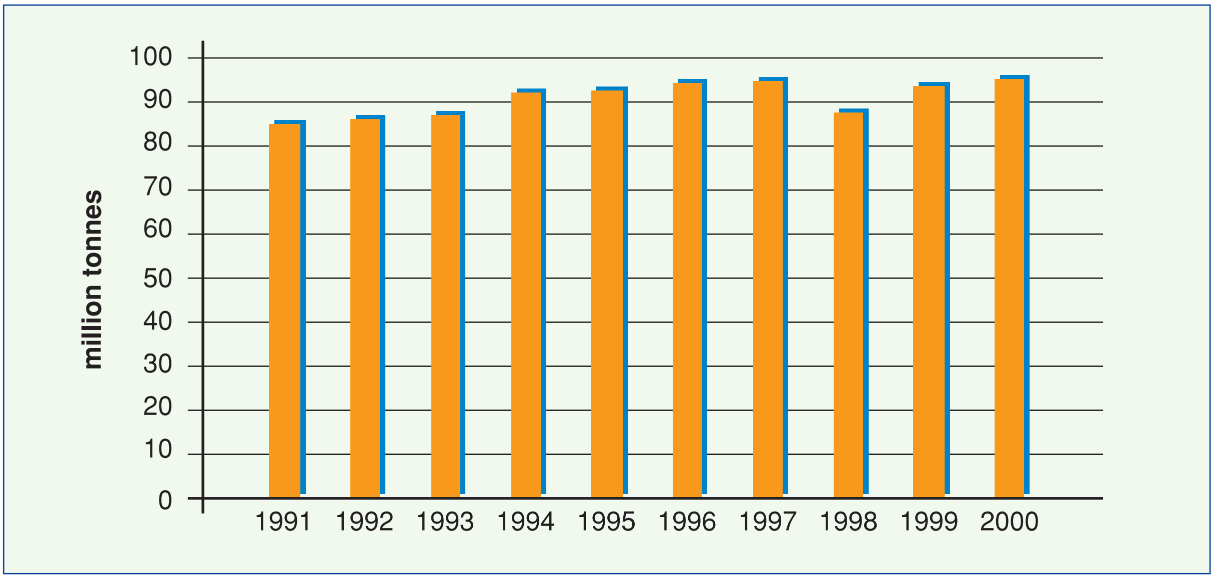


Figure 3. Global capture fisheries production 1991-2000 (FAO 2002b)

Table 1. Value of total capture fisheries production in 1991 and 2000 (FAO 2002b)

Environment	1991 (tonnes)	2000 (tonnes)	Average annual increase (%)
Marine areas	78 301 736	86 047 604	1.1
Inland waters	6 235 251	8 801 070	3.9
Total production	**84 536 987**	**94 848 674**	**1.3**

In addition to the marine capture fisheries output that appears in statistical returns, a large quantity of the catch is discarded at sea because it consists of unsuitable species or sizes for marketing. James (1995) estimated that discards may amount to some 27 million tonnes annually. If this level of discards has continued, the total capture fisheries harvest may have been close to 122 million tonnes in 2000. Not all capture fisheries production is used for human consumption. 33.7 million tonnes was used for other purposes, mainly fishmeal and fish oil production in 2000 (FAO 2002d). Thus the capture fisheries yielded 61.1 million tonnes of foodfish (fish destined for human consumption) in that year, while aquaculture provided another 35.6 million tonnes (FAO 2002a). Aquaculture therefore contributed about 37 percent of the global foodfish supply in 2000.

Marine fish contributed 71.8 million tonnes to capture fisheries production in 2000, while the catches of diadromous and freshwater fish were 1.8 million tonnes and 6.9 million tonnes respectively. To date, there are some 25 000 different known fish species, of which 15 000 are marine (Nelson 1994). However, 75 percent of the world's marine fishes landings come from only 200 species (~1 %). More than 2 500 species of reef-fish inhabit the Indonesian and Philippine region, and 35 percent of the world fish species are found in Indonesia alone. These biologically important areas are now being seriously threatened by the Live-Reef Food Fish Trade (LRFFT). The depletion of reef stocks in Southeast Asia has resulted in growing pressure on the resources of adjacent regions, especially the islands of the South Pacific (The Nature Conservancy 2002).

Fishery resources in general are heavily exploited. Recently it has been reported (FAO 2002c) that only 25 percent of the major marine fish stocks or species groups for which information is available are under exploited or moderately exploited. About 47 percent are fully exploited and 18 percent overexploited; the remaining 10 percent of stocks are significantly depleted. The worst affected stocks are in the Atlantic, the Central East and Northeast Pacific, the Black Sea and the Mediterranean (FAO 2000).

In 2000 (Figure 4), the Asian region contributed 48 percent of global fisheries production in marine and inland areas (45.4 million tonnes), followed by South America (18.0 million tonnes) and by Europe (16.0 million tonnes).

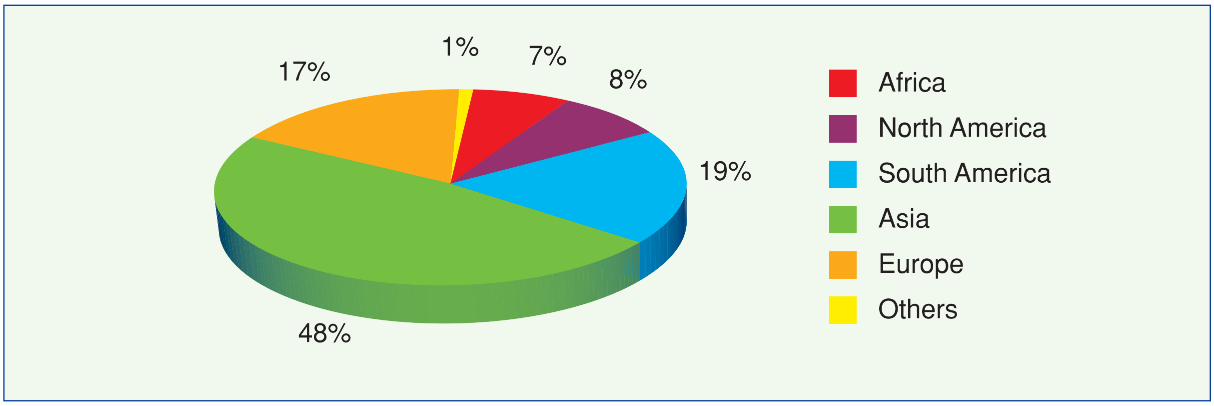


Figure 4. Global capture fisheries production (marine and inland) by region in 2000 (FAO 2002b)

There appears to be little likelihood that global fisheries can increase production, and it is likely that there will be a gradual fall over the following decades. There will also be increasing pressure on high value stocks, with the inherent risk of overfishing or unreported fishing, leading to a reduction in recruitment to these valuable resources. More closures of fisheries seem inevitable, resulting in a loss of income and traditional livelihoods for coastal communities. With the demand for fish products set to increase, only aquaculture can fill the gap between demand and supply, and has the potential to replace incomes lost from fishing.

Trends in global aquaculture

In 2000, global aquaculture production of foodfish (fish, crustaceans and molluscs) totalled 35.6 million tonnes, valued at nearly US$ 51 billion (FAO 2002a). Asian aquaculture farmers contributed 89 percent of the production valued at US$ 40.8 billion (80 percent of the total value). Asia thus appears to completely dominate aquaculture production (Figure 5). However, this does not mean that aquaculture in the rest of the world is unimportant. Figure 6 shows the proportion of aquaculture output produced in other continents.

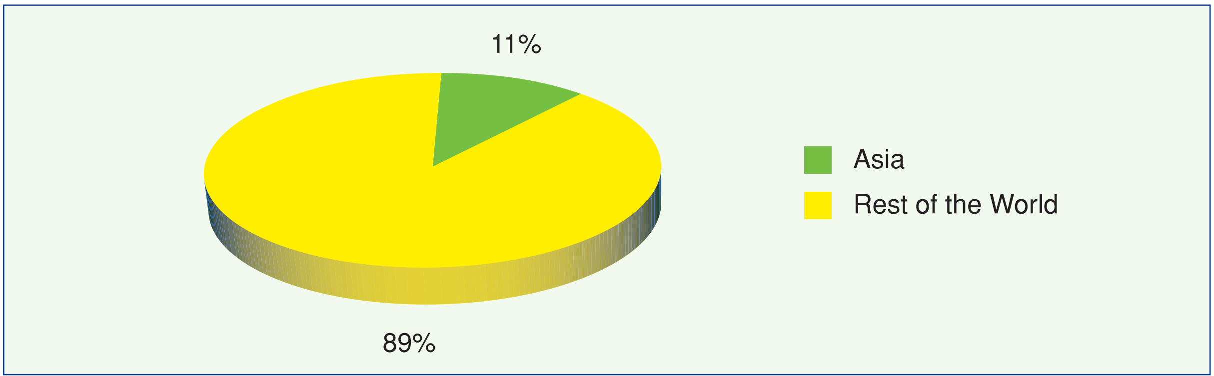


Figure 5. Proportion of foodfish produced by aquaculture in Asia (FAO 2002a)

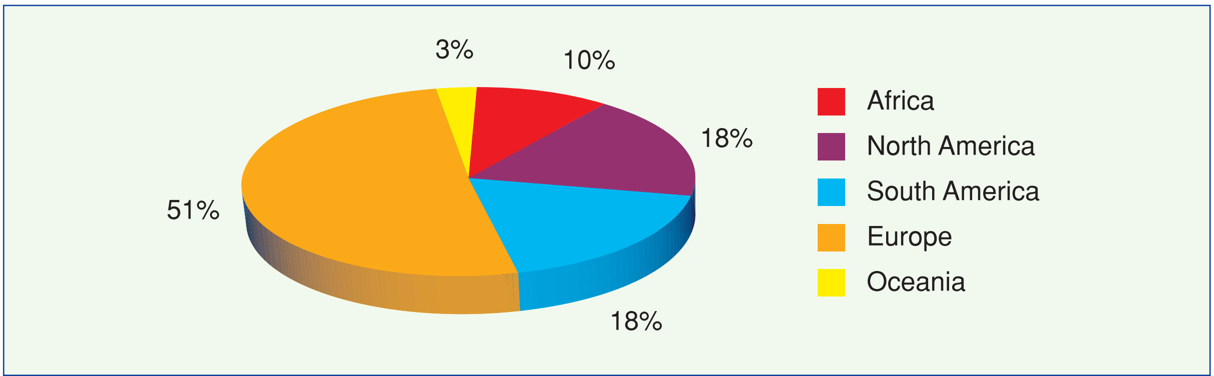


Figure 6. Proportion of foodfish produced by aquaculture in other continents (excluding Asia) (derived from FAO 2002a)

In 2000, nearly 84 percent of total aquaculture yield (including aquatic plants) was produced in low-income food-deficit countries (LIFDCs); China is dominant, with 32 million tonnes. However, when aquatic plants are excluded, only four of the top ten aquaculture producers of foodfish (China, India, Indonesia, Bangladesh) are LIFDCs (Figure 7). This in no way belittles the importance of aquaculture in other LIFDCs with a lower production than the top ten.

Global production of foodfish through aquaculture (Figure 8) has increased from 4.7 million tonnes in 1980 and 13.1 million tonnes in 1990 to 35.6 million tonnes in 2000 (FAO 2002a).

Global aquaculture production of foodfish was valued at nearly US$ 50.9 billion in 2000 (Figure 9). The value of the sector's foodfish production grew at an annual average of nearly 8 percent between 1991-2000.

So far, farming in freshwater has dominated foodfish production through aquaculture (FAO 2002a). However, the proportion grown in marine waters is increasing (32 percent in 1991; 36 percent in 2000). In addition, because of its greater average unit value, foodfish reared in marine

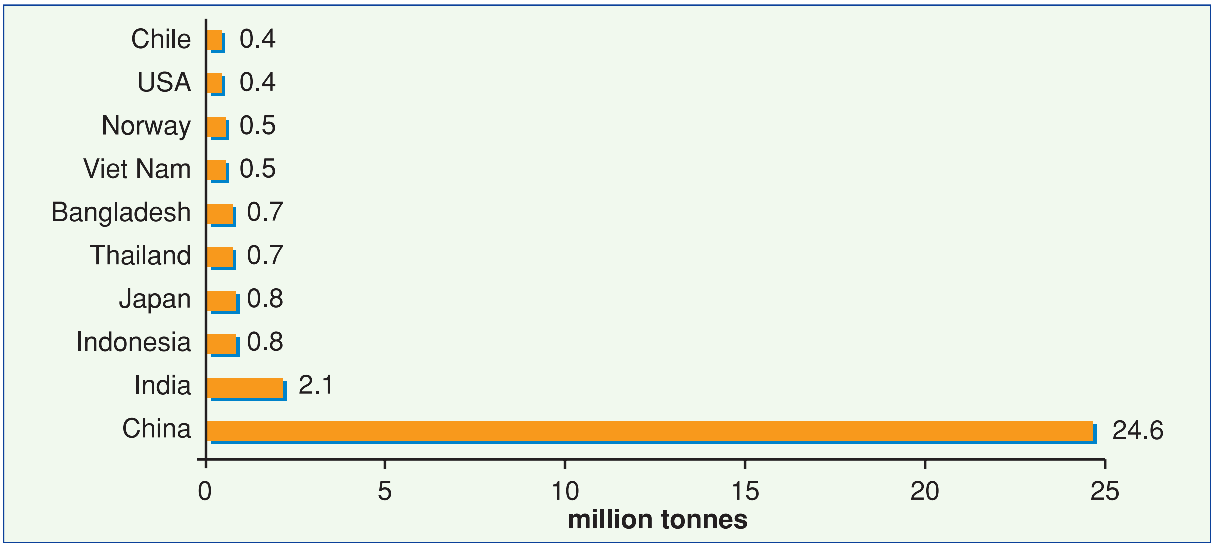


Figure 7. Top ten producers of foodfish through aquaculture in 2000 (FAO 2002a)

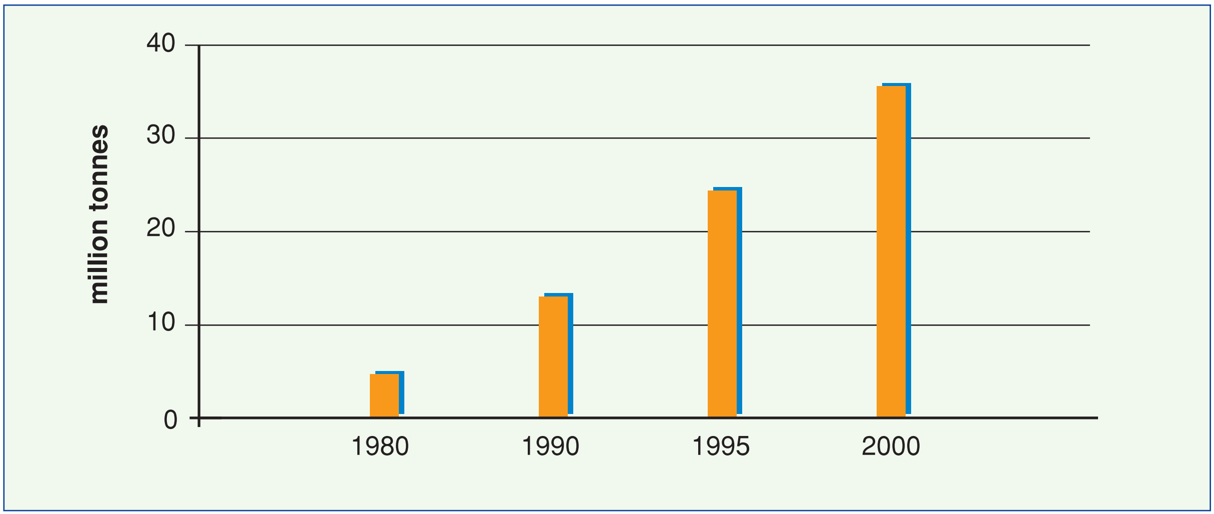


Figure 8. Trends in global aquaculture production (FAO 2002a)

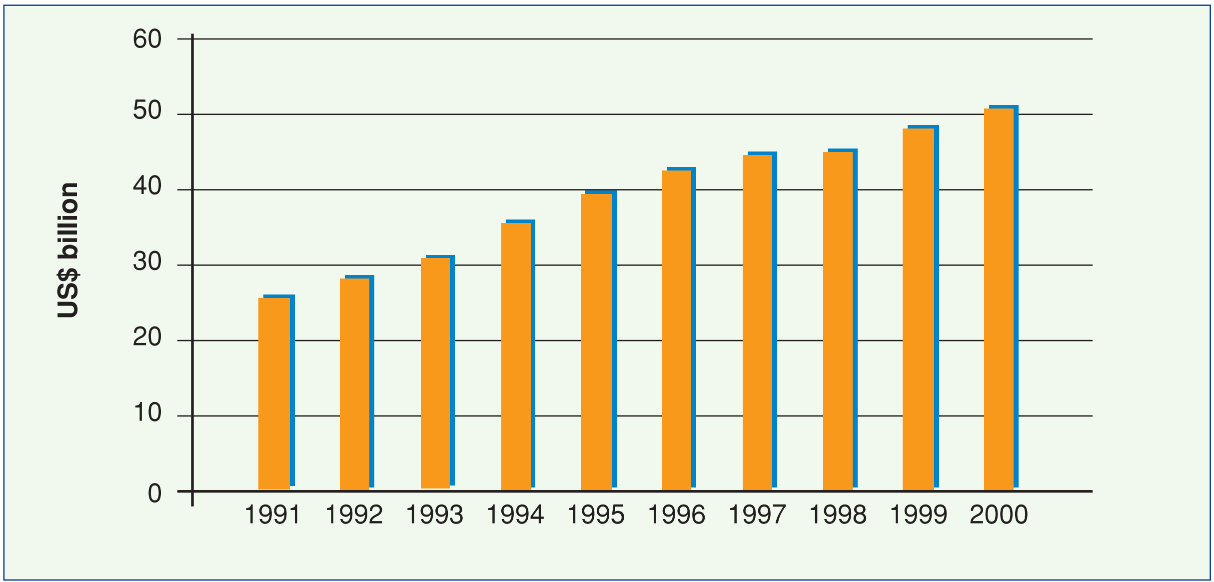


Figure 9. Trends in the value of global aquaculture products (FAO 2002a)

and brackishwater represents a higher proportion of the global total value of aquaculture than in freshwater (54 percent in 1991; 51 percent in 2000). In 2000, 81 percent of the total foodfish production from marine and brackishwater was reared in Asia, while 11 percent was produced in Europe (Figure 10).

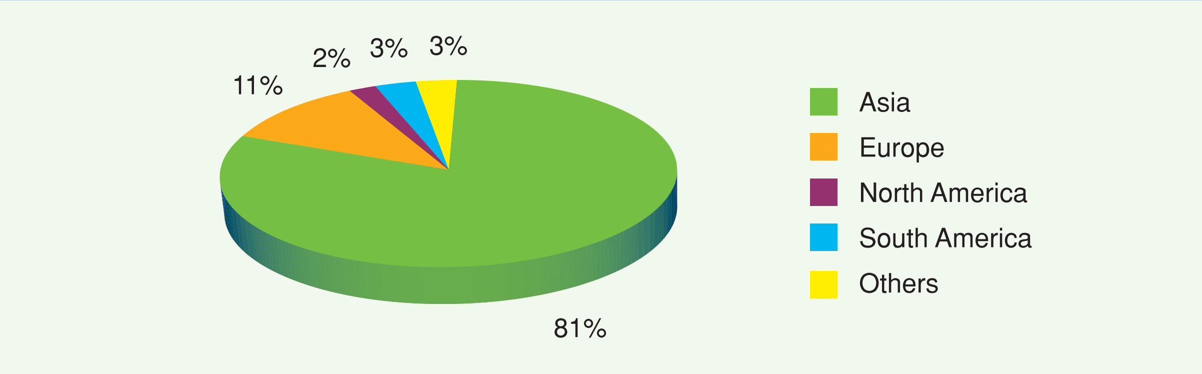


Figure 10. Marine and brackishwater aquaculture production by region in 2000 (FAO 2002a)

In marine and brackishwater areas, the most productive continent was Asia (12.2 million tonnes) and the highest production was in China (9.4 million tonnes). The top ten producing countries in these environments are shown in Figure 11.

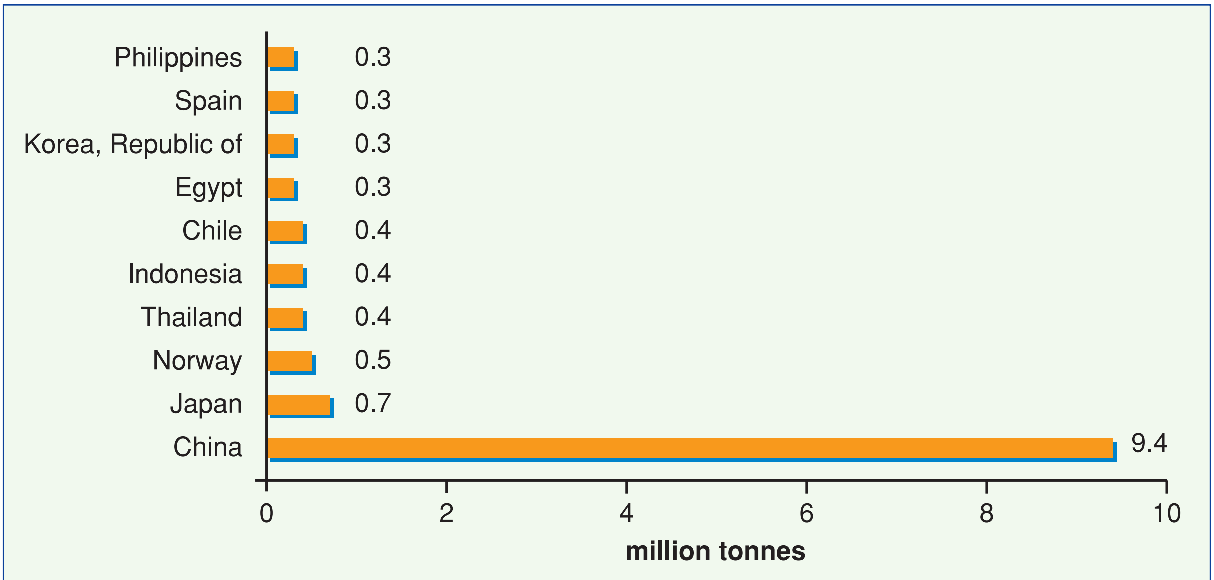


Figure 11. Top ten producers of marine and brackishwater foodfish through aquaculture in 2000 (FAO 2002a)

Between 1991 and 2000, the average annual rate of expansion in the production of foodfish in marine waters (12.6%) was greater than in any other environment (Table 2). In brackishwater, the annual expansion rate was very much less (4.2%). These rates of expansion are in marked contrast with the situation in the capture fisheries (Table 1).

Table 2. Global aquaculture production in 2000 compared to 1991 (FAO 2002a)			
Environment	**1991 (tonnes)**	**2000 (tonnes)**	**Average annual increase (%)**
Marine waters	4 410 696	12 861 611	12.6
Brackish waters	1 450 201	2 091 956	4.2
Inland waters	7 863 317	20 631 544	11.3
Total production	**13 724 214**	**35 585 111**	**11.2**

Global aquaculture has been in a dynamic phase of growth for more than 30 years. Its average annual expansion rate between 1970 and 2000 was 9.2 percent, compared to only 2.8 percent for terrestrial farmed meat production systems (FAO 2002c). This trend can be attributed to several key factors:

- the closure of the life cycles for important commercial species; e.g. salmon, seabass, seabream, penaeid shrimps, etc;
- the development of hatchery technology to supply on-growing units with juveniles outside of the normal availability seasons;
- the development of on-growing technology that can be used in exposed locations, in particular in offshore cages;
- the manufacture of specially formulated feeds which enhance production and maintain fish health;
- better understanding of fish biology and diseases, and the development of treatments for disease control; and
- the development of management systems that optimize production.

However, the sector still lacks the knowledge and experience to market the production now being achieved successfully. All the species that have been commercialized have suffered from price declines, due to the poor development of markets to absorb the new volumes now being produced. This problem is further aggravated by the fragmented nature of the sector, and the situation is unlikely to change until a more coordinated approach is adopted.

Capture-based farmers have, to a large degree, avoided this disjointed approach so far (2002). This is largely due to the fact that many operations are joint ventures and that they supply a common market with capture fisheries, e.g. supplying bluefin tuna to the Japanese market.

Good marketing strategies and response to consumer perceptions will be the most important issues to tackle if the industry is going to continue its rapid growth. The industry will also have to address the concerns of environmental campaigners, in order to avoid adverse market reactions.