CAPTURE-BASED AQUACULTURE

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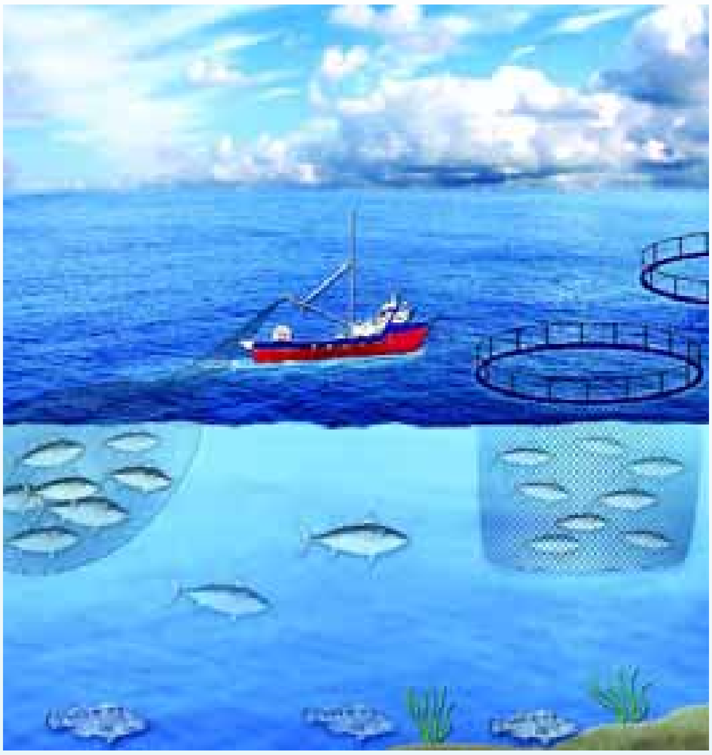
THE FATTENING OF EELS, GROUPERS, TUNAS AND YELLOWTAILS



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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.

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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.

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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".

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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 "<u>culture-based fisheries</u>" (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 "<u>capture-based aquaculture</u>". This term represents an overlap between fisheries and aquaculture and is defined as follows:

<u>Capture-based aquaculture</u> 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.

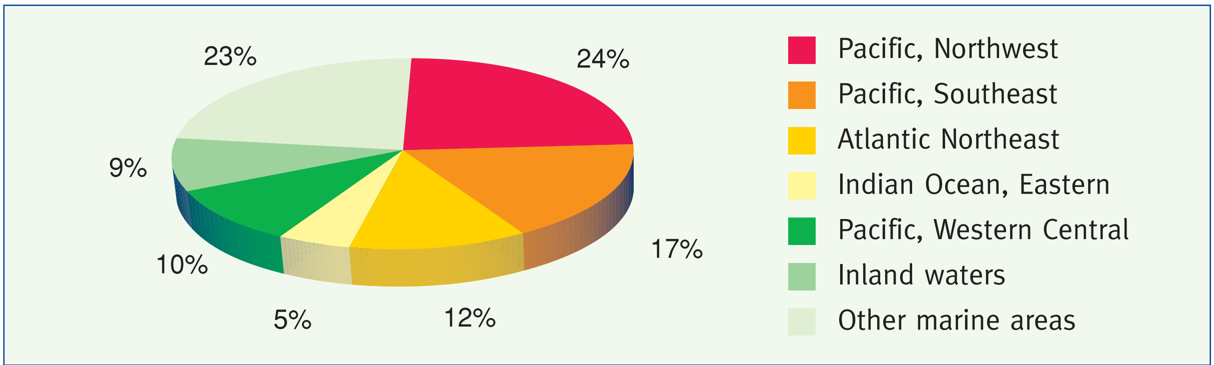


Figure 1. Global fish landings per fishing area in 2000 (FAO 2002b)

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%).

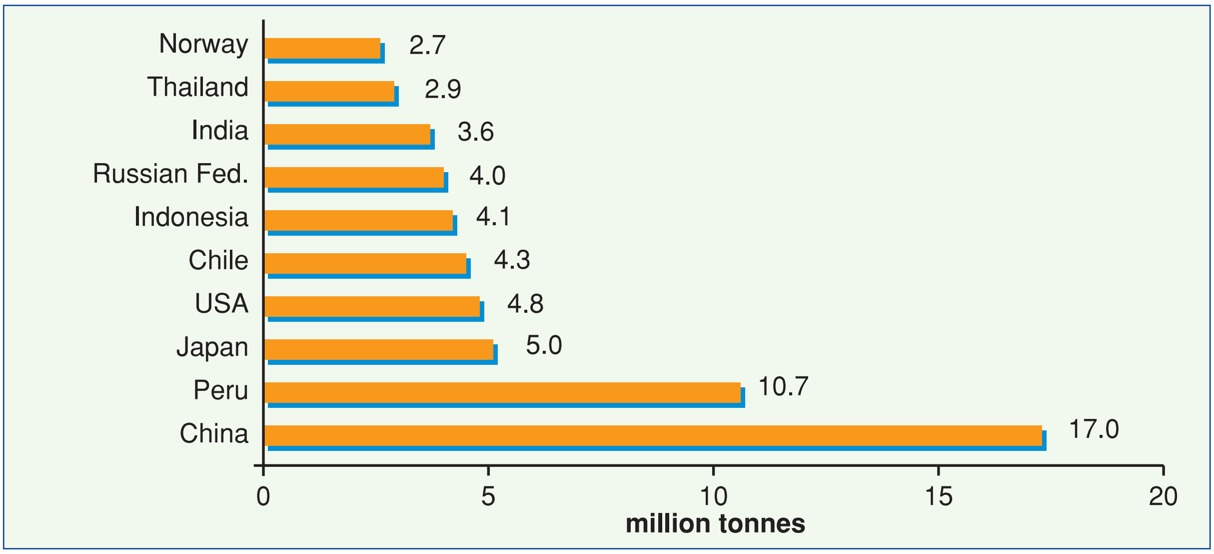


Figure 2. Fish landings from the top ten fishing nations in 2000 (FAO 2002b)

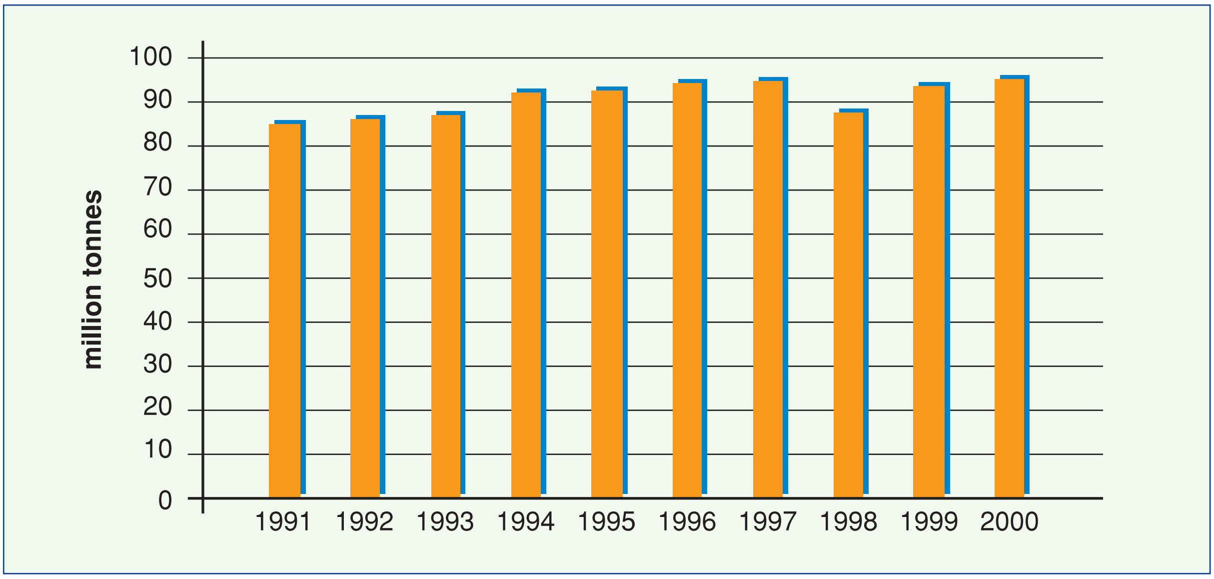


Figure 3. Global capture fisheries production 1991-2000 (FAO 2002b)

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).

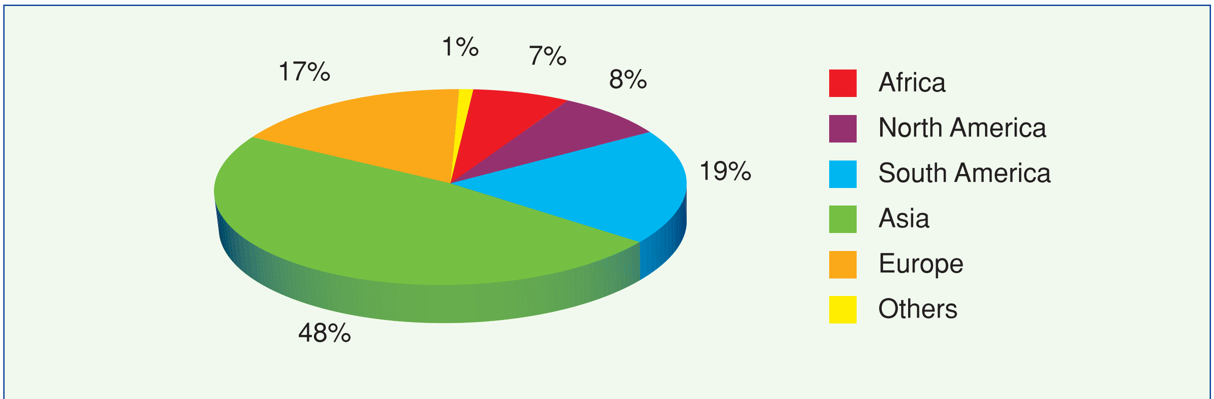


Figure 4. Global capture fisheries production (marine and inland) by region in 2000 (FAO 2002b)

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.

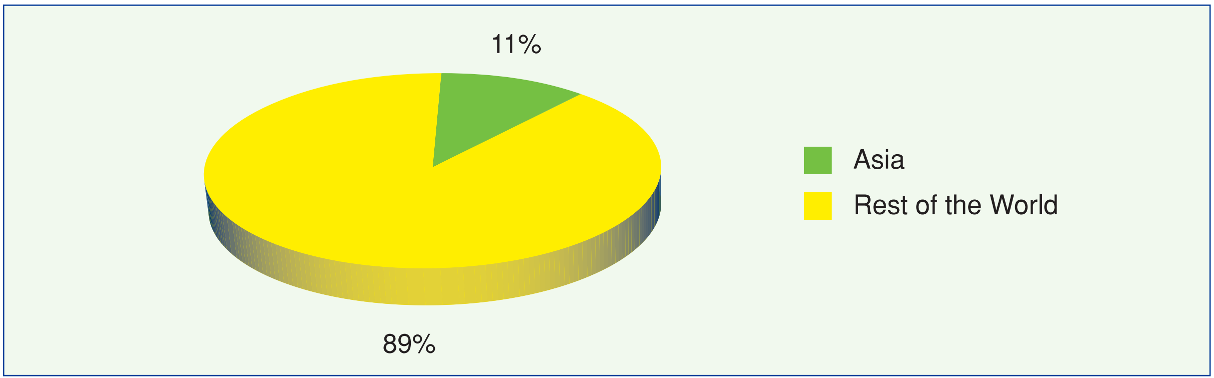


Figure 5. Proportion of foodfish produced by aquaculture in Asia (FAO 2002a)

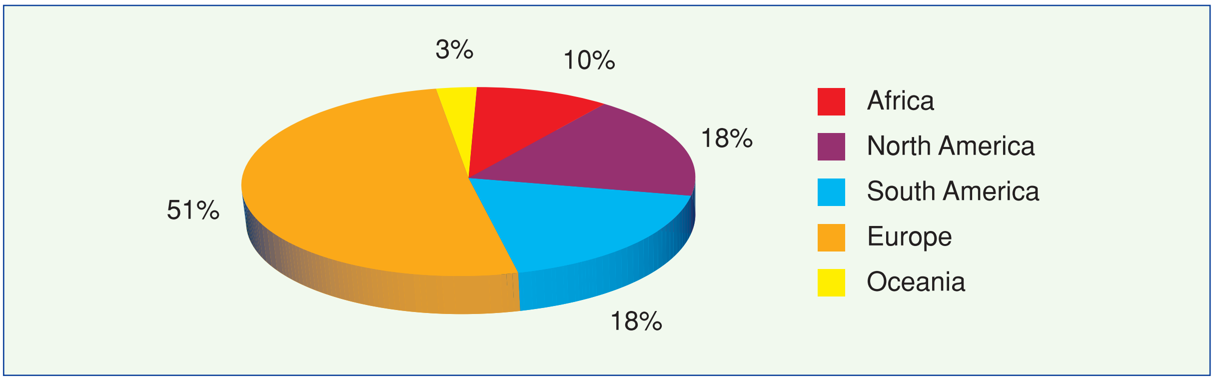


Figure 6. Proportion of foodfish produced by aquaculture in other continents (excluding Asia) (derived from FAO 2002a)

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

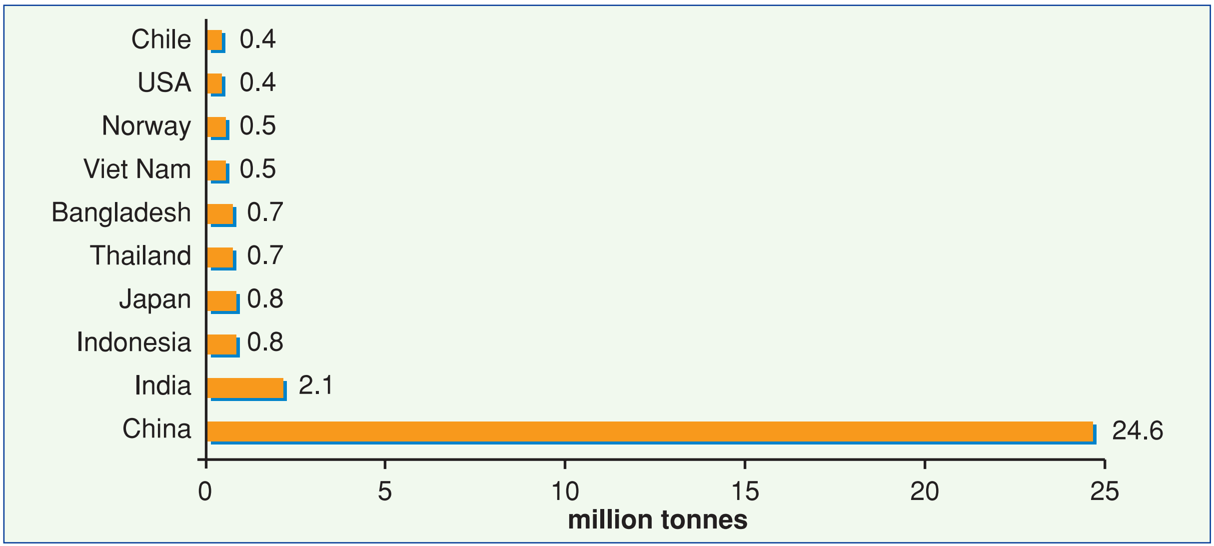


Figure 7. Top ten producers of foodfish through aquaculture in 2000 (FAO 2002a)

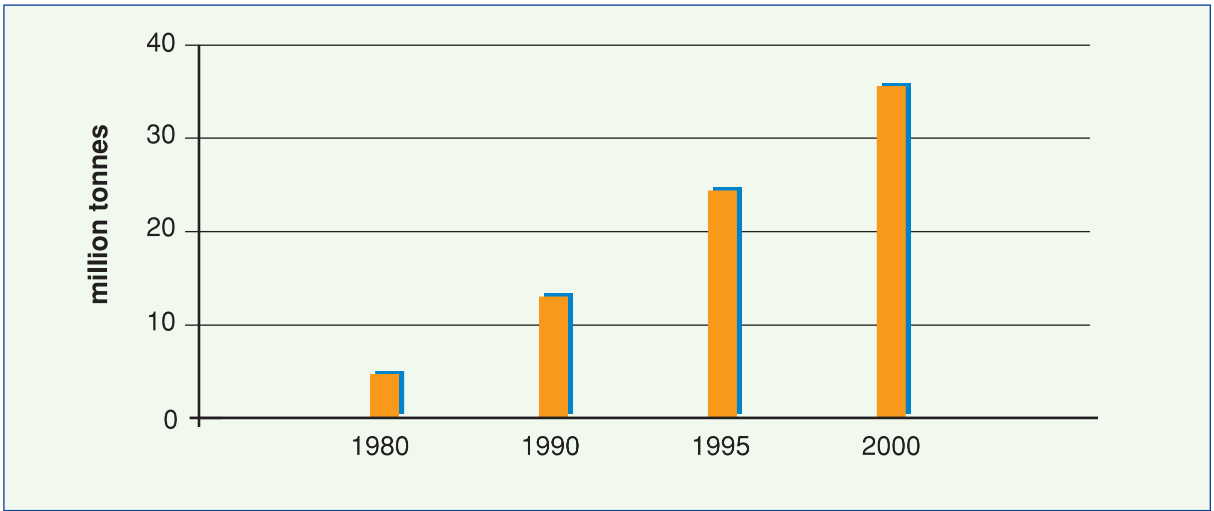


Figure 8. Trends in global aquaculture production (FAO 2002a)

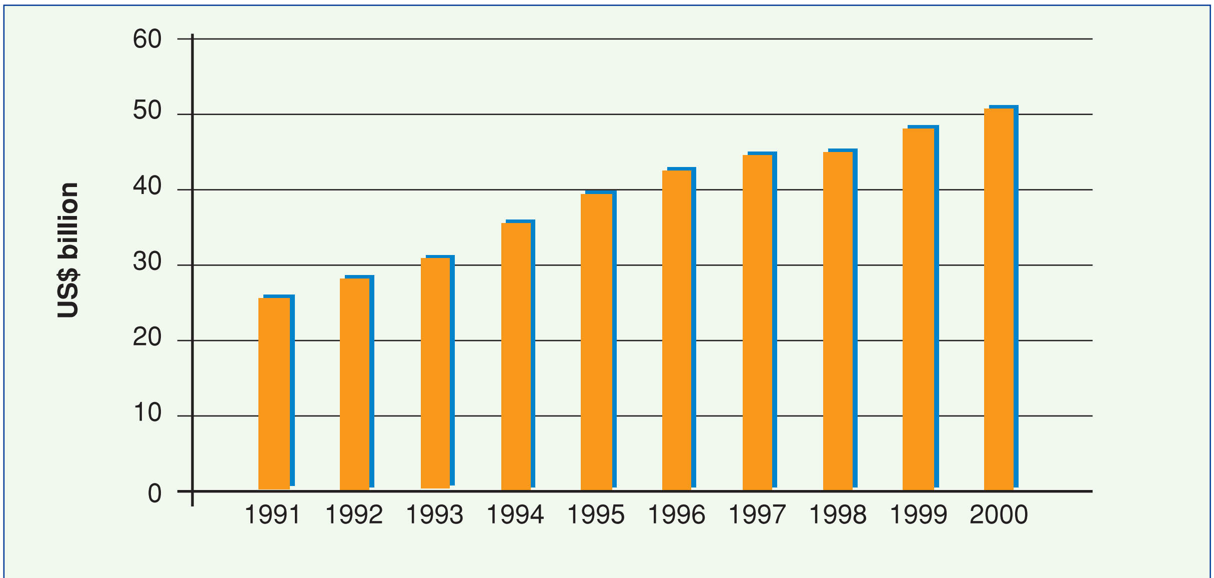


Figure 9. Trends in the value of global aquaculture products (FAO 2002a)

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).

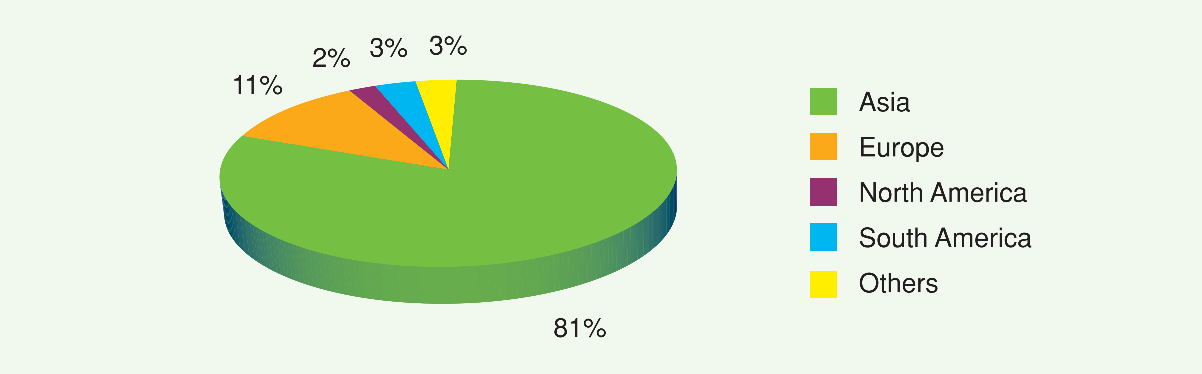


Figure 10. Marine and brackishwater aquaculture production by region in 2000 (FAO 2002a)

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.

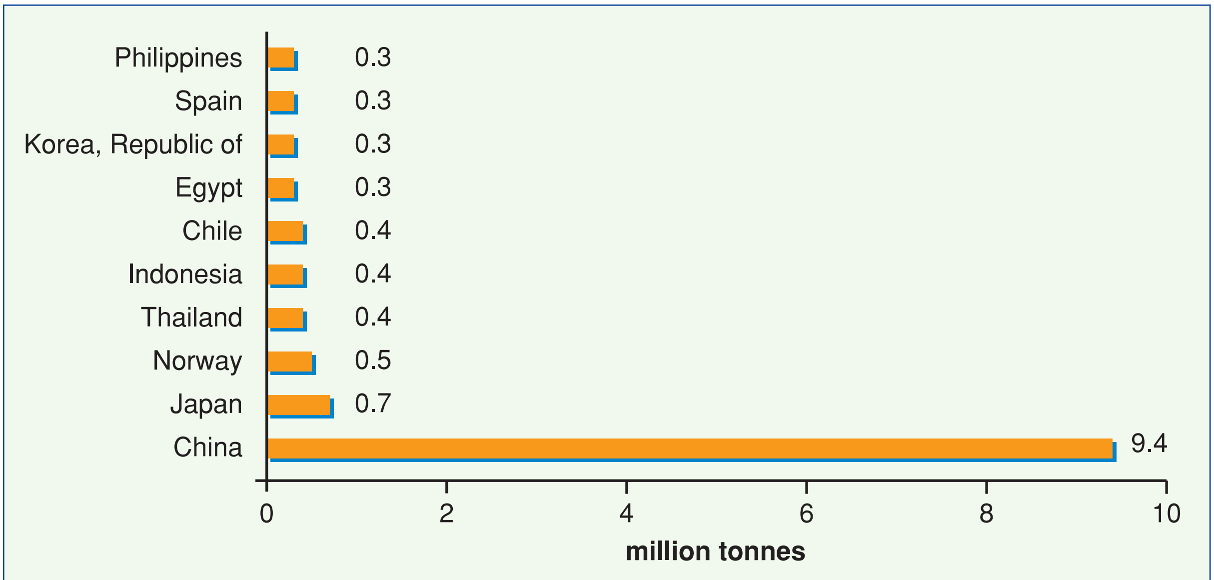


Figure 11. Top ten producers of marine and brackishwater foodfish through aquaculture in 2000 (FAO 2002a)

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.

chapter 2

SPECIES SELECTION

2

SPECIES SELECTION

Introduction

The major characteristics that determine the suitability of a species for aquaculture are its potential marketability, its growth rate and its ability to function under culture conditions. For selection, economic considerations should be even more important to an aquaculturist than biological factors.

Carnivorous species generally need a high protein diet and are therefore considered to be more expensive to rear, even though costs will depend largely on the local availability and price of the necessary feedstuffs. However, compensating for high feeding costs, most carnivorous species command higher market prices. Such species generally have greater market potential and therefore attract substantial investment (Pillay 1995). This is true for most types pf aquaculture practices, but for capture-based aquaculture it is of special importance, as most of the species farmed are carnivorous. The species groups used in capture-based aquaculture include molluscs (oysters, mussels, scallops), crustaceans (shrimps, crabs) and finfish (eels, grey mullets, milkfish, yellowtails, groupers, rabbit fish, tunas) (Pillay 1995; Hair, Bell and Doherty 2002).

This report focuses on four target species groups: eels, groupers, tunas and yellowtails. These have been selected for their high level of importance in capture-based aquaculture as they have rapid grow-out and high market demand; in addition, there is an expanding interest in their culture and technological innovations are being developed to aid their rearing (Yamaoka *et al.* 2000; Bombeo-Tuburan *et al.* 2001; Doumenge 1999; Nakada 2000).

Groupers are popular food fish farmed in Southeast Asia and have the potential to become an important aquaculture species, owing to their fast growth, efficient feed conversion, high market prices and reduced availability from wild resources (Randall 1987; Beets and Hixon 1994; Sluka and Reichenbach 1996; Boonyaratpalin 1997; Morris, Roberts and Hawkins 2000; Millamena 2002). The demand for groupers has grown markedly over the last two decades in parts of South-East Asia. The value of live groupers depends on the species. In Hong Kong, for example, prices range from US$ 8-31/kg (INFOFISH 2003). Groupers are also good candidates for aquaculture for gastronomical reasons; they are valued as one of the highest quality seafoods in many parts of the world (Shiau and Lan 1996). Groupers are covered in Chapter 4 of this report.

The amberjack or yellowtail is another good candidate species for the diversification of farmed fish products because of its high growth rate and good performance in captivity (acceptance of food, low mortality). Yellowtails have a good market especially in Japan; this has developed over the last 30 years due to capture-based aquaculture production. One of the most interesting characteristics of these fish is that they can be processed and marketed as a range of products, e.g. whole, fillets, steaks, etc. This is one of the few cases where a farm-raised fish is unanimously considered superior in quality to fish caught from the sea, and fetches a much higher price in the market. In Japan, the traditional production of the Japanese amberjack, also known simply as "yellowtail" (*Seriola quinqueradiata*) is being amplified by the culture of other species from the same group, namely the greater amberjack (*Seriola dumerili*) and the goldstriped amberjack (*Seriola lalandi*). *S. lalandi* is highly valued for fresh consumption in Japan, as "*sushi*" and "*sashimi*"; *S. dumerili* has potential for culture in the Mediterranean (Spain, Italy, Greece and France) (Nash 1995; Nakada 2000). South Australia has begun to harvest

S. lalandi, to satisfy the increasing export demand. In Japan, market prices for the Japanese amberjack, greater amberjack and goldstriped amberjack, mainly for "*sashimi*" consumption, range from ¥ 1 200-3 000/kg (Nakada 2000). The capture-based aquaculture of yellowtails is described in chapter 6 of this report.

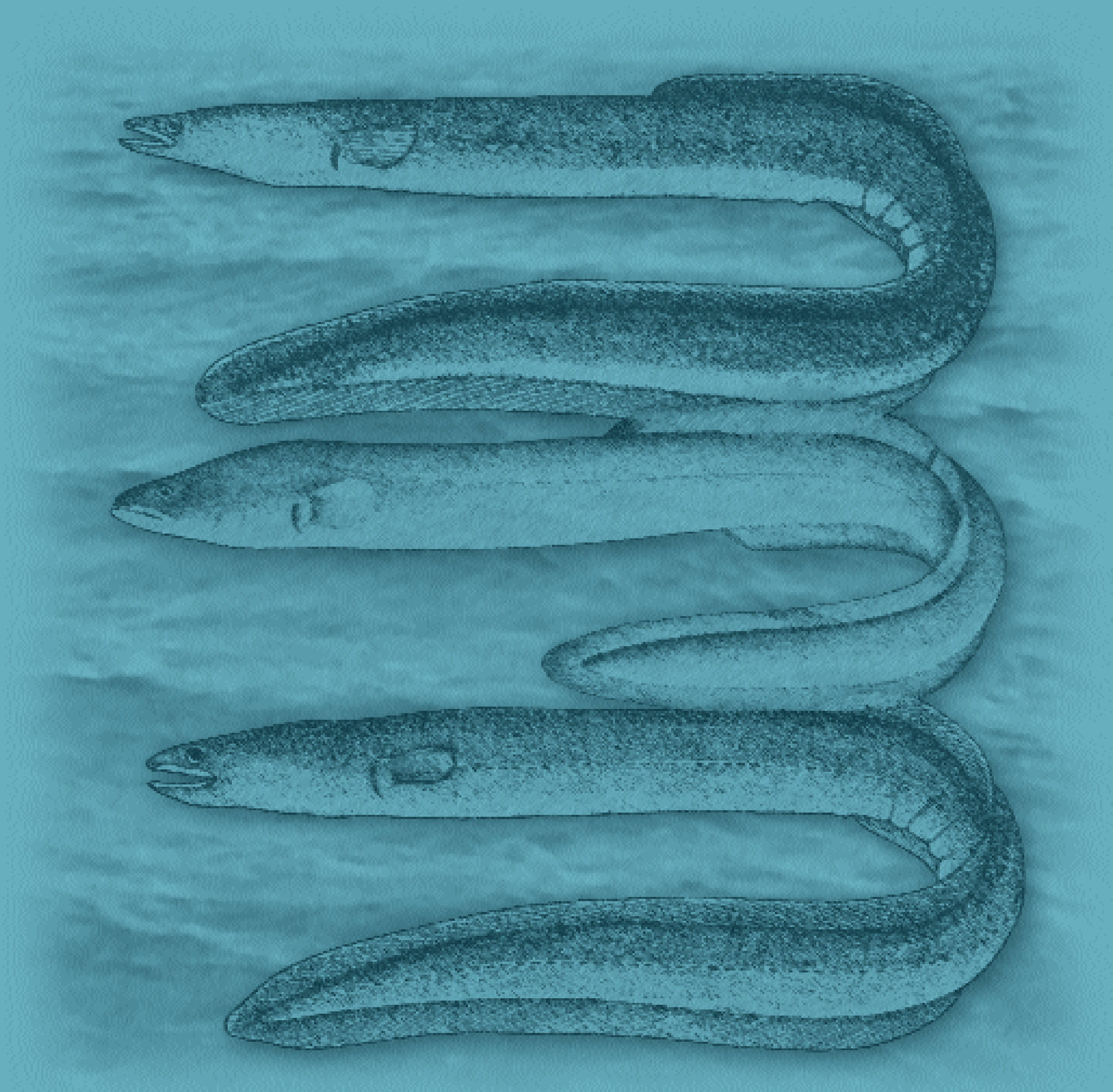
Eels are also an important species for commercial aquaculture; they are considered a delicacy in many countries. Traditionally, Western Europe and Japan have been the areas where demand is highest. Eels can fetch up to US$ 32/kg, twice the price of good-quality shrimp. In Japanese restaurants, where eels are considered a healthy food, an eel dish can cost between US$ 20 and US$ 32 per portion. Global demand for eels exceeds 200 000 tonnes annually and eel aquaculture has developed into a highly specialized industry. Chapter 3 of this report deals with the capture-based aquaculture of eels.

The fourth of our selected species, increasingly the object of interest to farmers, is the bluefin tuna. Over the past few years, there has been a rapid increase in the practice of capture-based tuna farming, which is described in chapter 5 of this report. Generally speaking, the major focus is on three populations: *Thunnus thynnus thynnus* in the North Atlantic and the Mediterranean, *Thunnus thynnus orientalis* in the North Pacific, and *Thunnus maccoyii* in Australia. These developments have been driven by the market demand for "*sushi*" and "*sashimi*" products in Japan, and many projects are joint ventures between local fishermen/fish farmers and Japanese companies. There are production centres in Japan, Australia, the Mediterranean and Mexico. Notwithstanding its high development costs, this dynamic sector of aquaculture has now established itself, and it stands as being the most profitable. The preference accorded to bluefin tuna is justified by the high prices paid on the Japanese market for it. Generally, prices are five times those paid for *Thunnus obesus* (big-eye) and ten times those for *Thunnus albacares* (albacore) (Doumenge 1999). Farmed bluefin tuna, destined for the uncooked fish market ("*sushi*" and "*sashimi*") has become a top quality product; with its higher fat content it is particularly suitable for "sushi". The fish that are raised by capture-based aquaculture can not only achieve substantial weight gains but, more importantly, increases in fat content, thus becoming more valuable. On the Japanese market, 1 kg of top quality tuna can be sold for up to US$ 600.

Capture-based aquaculture practices involve a thorough understanding of the behaviour, habitat and general environmental requirements of each species, as well as knowledge of its reproductive biology, nutritional requirements, larval and juvenile physiology, culture systems, and "seed" availability. In addition, the susceptibility of each species to disease under culture conditions needs investigation. However, despite the level of technology that has developed in capture-based aquaculture, all will be wasted unless market prices can support further investment, and future research.

chapter 3

EELS



3

EELS

Introduction and species identification

The family *Anguillidae*, order Anguilliformes, subclass Actinopterygii (ray-finned fish) includes (FishBase 2002) 17 species (two of them with two subspecies): *Anguilla anguilla, A. australis, A. bengalensis (*spp. *A. bengualensis* and *A. labiata), A. bicolor (*spp. *A. bicolor* and *A. pacifica), A. celebensis, A. diffenbachii, A. interioris, A. japonica, A. malgumora, A. marmorata, A. megastoma, A. mossambica, A. nebulosa, A. nigricans, A. obscura, A. reinhardtii* and *A. rostrata*.

Eels are catadromous, migrating from rivers and other inland water bodies to the sea to breed; the young return to the edge of the continental shelf as leptocephali and, having metamorphosed into glass eels, eventually migrate up the rivers. The Japanese eel (*A. japonica*) spawns in mid Pacific, but the European eel (*A. anguilla*) and American eel (*A. rostrata*) migrate to the middle of the Atlantic Ocean to spawn in the Sargasso Sea.

For a long time, the life history of the eel was a mystery, and much of it remains so today. Since eels have different life stages, it is important to name them, as defined[1] by EIFAC/ICES (2001). The stages are defined[1] as follows:

- **Leptocephalus** – the oceanic, pelagic larval eel. For *A. rostrata* this stage lasts several months.
- **Glass eel** – small, transparent eel formed by metamorphosis of leptocephali. Metamorphosis occurs at sea, perhaps near the edge of continental shelf. Glass eels are un-pigmented elvers. They enter coastal waters and estuaries and many ascend rivers during the winter and spring.
- **Elver** – small juvenile eel. The term sometimes used vaguely, but really refers to the first year in continental waters.
- **Yellow eel** – juvenile eel residing in continental waters. The colour of the specimen is not diagnostic of this life stage. This stage typically lasts several years.
- **Silver eel** – a sexually maturing eel, migrating to the oceanic spawning area. The colour of the specimen is not diagnostic of this life stage. Transitions to this stage includes changes in body colour, structure and physiology of the swim bladder, and of the eye.

The larvae of the European eels (*Anguilla anguilla*) travel with the Gulf Stream across the Atlantic and reach Europe after 3 years, at a size of around 45 mm. The glass eels migrate up the rivers, crossing all kinds of natural challenges, sometimes by piling up their bodies in large numbers to reach even the smallest creeks. They can even slide over wet grass and dig through wet sand in order to reach headwaters upstream and ponds. In freshwater they start pigmentation, turning into elvers and feeding on small crustaceans, worms and insects. They may remain in this form for up to 14 years, and reach a length of 60 to 80 cm. They are then called yellow eels because of their golden pigmentation. In July, their instinct drives them back toward the sea, even crossing wet grasslands during the night to reach their rivers (Frost *et al.* 2000).

1 Note: although these definitions are quite distinct there is often confusion and conflicting data for catches, mostly between glass eels and elvers.

The American eel (*Anguilla rostrata*) migrates from estuaries and freshwaters along the eastern coast of North and Central America to the Sargasso Sea near Bermuda to spawn and die. Eel larvae develop at sea and return via ocean currents to the continental shelf and enter coastal estuaries as glass eels or elvers. They reside, feed and grow in coastal estuaries and headwaters before returning to the sea to spawn and complete the cycle (Field 1996). Males reach sexual maturation after 6-9 years (150 g), females after 8-12 years (500 g) (Tibbetts 2001).

In Asia, the Japanese eel (A*nguilla japonica* or *unagi* in Japanese) spends from 5 to 20 years in freshwater and grows to a size of about 45 cm or longer before reaching sexual maturity. At this time eels descend to the sea toward their spawning grounds. They spawn in the Pacific Ocean to the west of the Mariana Islands (Tzeng *et al*. 2000). The spawning area of Japanese eels was only discovered in 1991, when it was found to be in the North Equatorial Current, west of the Mariana Islands on a salinity front near 15 degrees N, 140 degrees E, 3 000 kilometres south from the growing habitat in East Asia (Kimura and Sugimoto 1994). After hatching, the transparent leaf-like larvae drift with the Kuroshio Current along the Western Pacific coast up to Japan. They are believed to be pelagic for 5-6 months, before metamorphosing into elvers and beginning their river ascent. At this time they are still totally transparent, have the body shape of an eel and are called glass eels. These glass eels are carried by tides into the estuaries of coastal rivers where they undergo further development to become elvers (up to 1-3 years of age), which by now have adopted the adult form in all respects other than size. The elvers then undertake a more active secondary migration into freshwater, the upper reaches of the rivers where they grow and develop into sexually mature adults before returning to the sea to spawn – at an average of 10-25 years of age.

Short-fin eels (*Anguilla australis*) have a natural distribution from Tasmania, north through Victoria, and up the east coast to Queensland. The short-fin eel is found only as far north as southeast Queensland. Every year, mature silver eels migrate from the east coast of Australia and New Zealand to the Coral Sea, where it is thought that they spawn at depths of around 300 m. Eels spawn only once in their lifetime, and after spawning it is presumed that the adult eels perish. Once the eggs hatch, ocean currents carry leptocephali back to the continental shelf. At around eighteen months of age they metamorphose into glass eels. The glass eels are carried by tides and currents back to shore and into coastal estuaries, where they undergo further development. Pigmentation occurs and the glass eels metamorphose into elvers. Elvers are an exact copy of the adult eel but are much smaller, ranging from 8-20 cm and 1-3 years of age. The elvers migrate upstream to occupy estuarine and river environments, where they mature into adult eels and apparently live for 15-20 years.

Eel fisheries and eel capture-based aquaculture are distinguished from almost all other fisheries because of the life cycle of the eel - that is extremely migratory (Frost *et al.* 2000). This report focuses on *Anguilla rostrata*, *A. australis*, *A. anguilla* and *A. japonica*, which are species that are distributed in specific locations worldwide. Tables 3-6 summarize the characteristics of these species, while Figures 12-19 illustrate their appearance and geographical location.

Anguilla anguilla (Linnaeus, 1758)

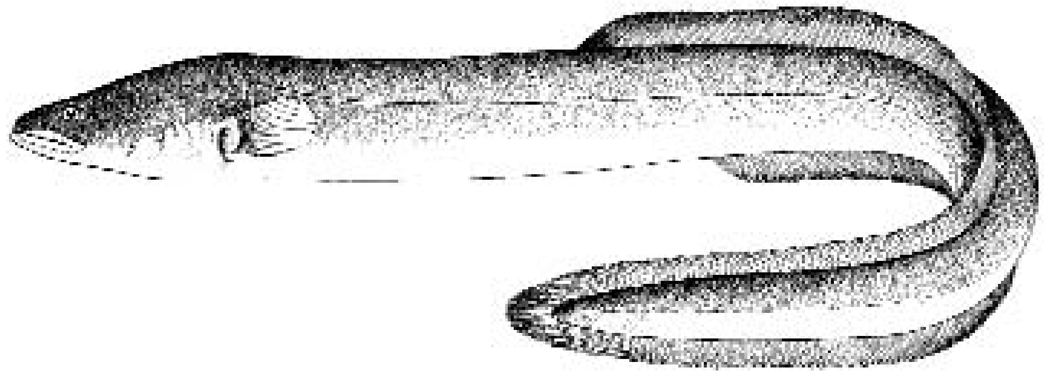


Figure 12. European eel (*Anguilla anguilla*) (FAO)

Table. 3. Characteristics of the European eel (*Anguilla anguilla*) (FishBase 2002, modified)

Common name	European eel
Size and age	Maximum size 133 cm TL (female); maximum female weight can be 6.6 kg, and for a male 2.8 kg; these fish can live for up to 85 years.
Environment	Demersal; lives in fresh, brackish and marine waters.
Climate and latitude	Temperate: 4-20°C between 70°N-25°N.
Resilience	Population doubling time is 4.5-14 years, with low resilience.
Distribution	Rivers of North Atlantic, Baltic and Mediterranean Seas. Continuous introductions into Asia and South and Central America, but not reproducing.
Biology and ecology	Is an individualist in all its stages. The spawning area is the Western Atlantic (Sargasso Sea). Spawning takes place in late winter and spring (McCleave *et al.* 1998). After reproduction, the leptocephali move, drifting on the Gulf Stream, during 3 years (Tesch 1977) to the coasts of Europe where they reach 8-9 cm in length before their metamorphosis into glass eels. Then they are transformed into elvers (young eels) before entering the continental coastal zones, where they start pigmentation, turning yellow. They live in freshwater (6-12 years for males and 9-20 years for females) under stones, in the mud or in crevices, feeding on small crustaceans, worms and insects. At 60-80 cm in length, they are sexually mature, turn into the silver form and begin a catadromous migration between October and January (July in Northern Europe) to the sea.
Importance	Commercial fisheries and aquaculture; gamefish; show aquarium.

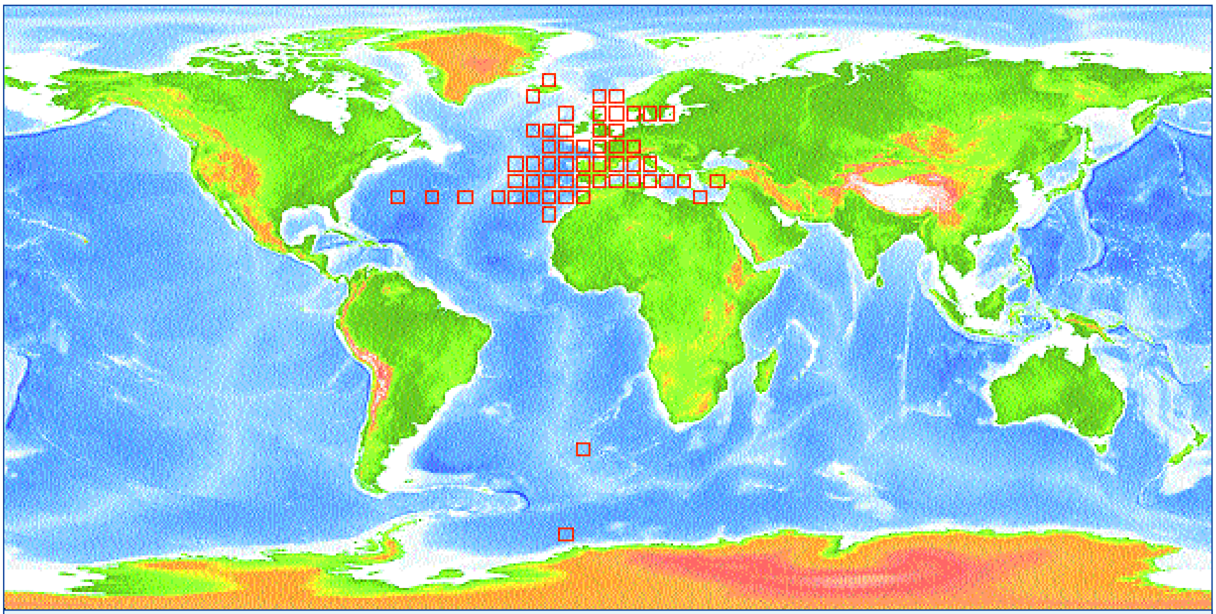


Figure 13. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Anguilla anguilla* (FishBase 2002)

Anguilla rostrata (Lesueur, 1817)

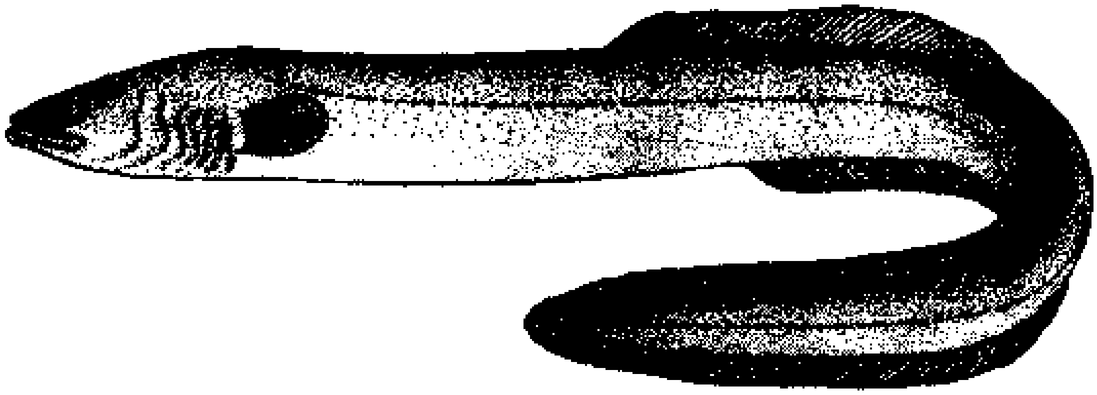


Figure 14. American eel (*Anguilla rostrata*) (FAO)

Table 4. Characteristics of the American eel (*Anguilla rostrata*) (FishBase 2002, modified)

Common name	American eel.
Size and age	Maximum size of 152 cm TL (male/unsexed) and 120 cm TL (female). Maximum weight is 7.3 kg; these eels can live for up to 43 years.
Environment	Demersal species; the female yellow and silver eels prefer freshwaters while males are found almost exclusively in salt or brackish waters with high oxygen content (Fahay 1978).
Climate and latitude	Subtropical, between 60°N-9°N; wide range of temperatures (Bigelow and Schroeder 1953) between 4-25°C, with yellow eels having an optimum of 16.7°C (Barila and Stauffler 1980) and silver eels of 17.4°C (Karlsson, Ekbohm and Steinholtz 1984).
Resilience	Population doubling time is 1.4-4.4 years with medium resilience.
Distribution	East North Atlantic, Atlantic coast of Canada, the USA to Panama and throughout much of the West Indies south to Trinidad.
Biology and ecology	Usually occurs in permanent streams with continuous flow. Hides during the day in undercut banks and in deep pools near logs and boulders. Feeds on larvae of Ephemeroptera, Odonata, Plecoptera, Coleoptera, Trichoptera, and Lepidoptera, as well as gastropods, oligochaetes, amphipods, isopods, mysids, and fish from the families Percidae, Cyprinidae, Ictaluridae, Catostomidae and Anguillidae (Lookabaugh and Angermeier 1992). Migrates in autumn to the Sargasso Sea to spawn (Wenner 1978). Adults are caught with eel pots and trot lines. Elvers and glass eels are caught with fine mesh fyke nets and dipnets.
Importance	Commercial fisheries and aquaculture; gamefish; show aquarium.

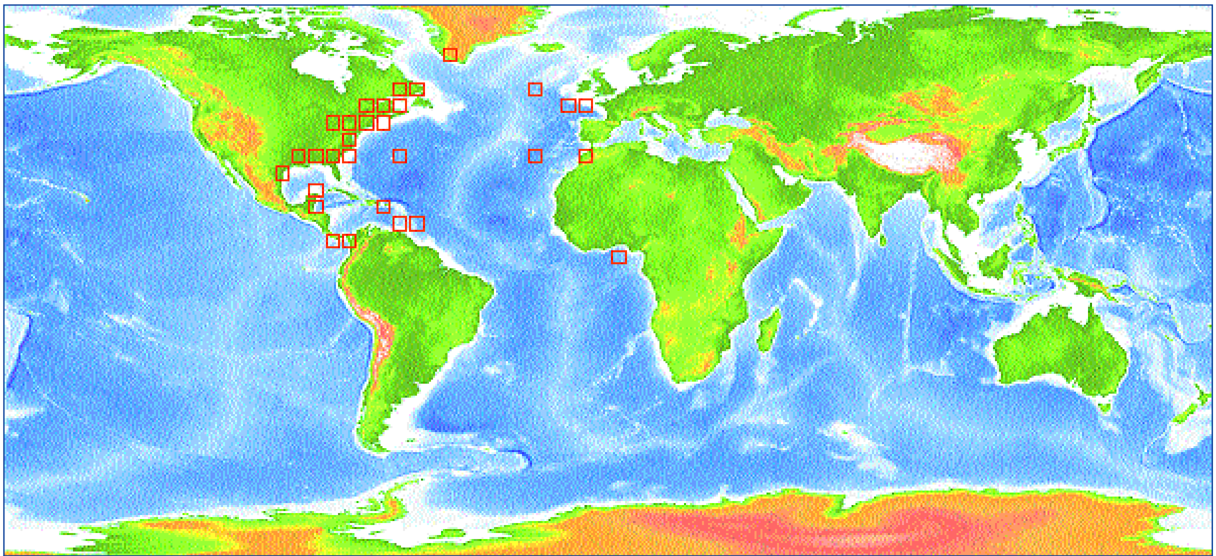


Figure 15. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Anguilla rostrata* (FishBase 2002)

Anguilla japonica (Temminck and Schlegel, 1847)

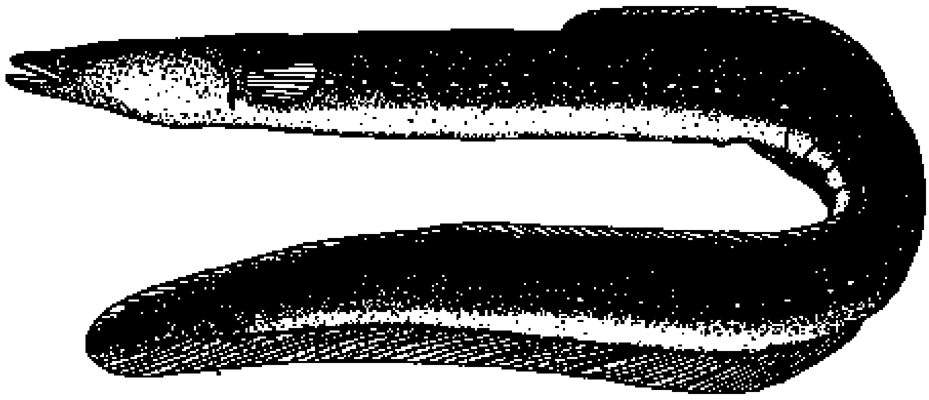


Figure 16. Japanese eel (*Anguilla japonica*) (FAO)

Table 5. Characteristics of the Japanese eel (*Anguilla japonica*) (FishBase 2002, modified)

Common name	Japanese eel.
Size and age	Maximum size of 150 cm TL (male/unsexed) and maximum published weight 0.76 kg. (?) [Approximate maximum size of female eels, according to Usui (1974) is 125 cm and 6 kg.]
Environment	Demersal species that lives in fresh, brackish and marine waters.
Climate and latitude	Tropical: 4-27°C at 42°N-22°N (Masuda *et al.* 1984).
Resilience	Population doubling time is 4.5-14 years with a low resilience
Distribution	This species is distributed in East Asia: Japan, Taiwan Province of China, Korea, China and Northern Philippines.
Biology and ecology	Japanese eels have a life cycle very similar to the other species described and the spawning area is located in the North Equatorial current west of the Mariana Islands, 3 000 km south of the growing habitat in East Asia (Kimura and Sugimoto 1994), not far from the coast. They enter the rivers as elvers within a year of hatching (Pillay 1995). Feeds on crustaceans, insects and fish (Man and Hodgkiss 1981).
Importance	One of the most expensive food fish in Japan, utilized fresh, smoked, canned and frozen; eaten steamed, broiled and baked (Frimodt 1995). Introduced elsewhere and is used in Chinese medicine (Aubray 1977).

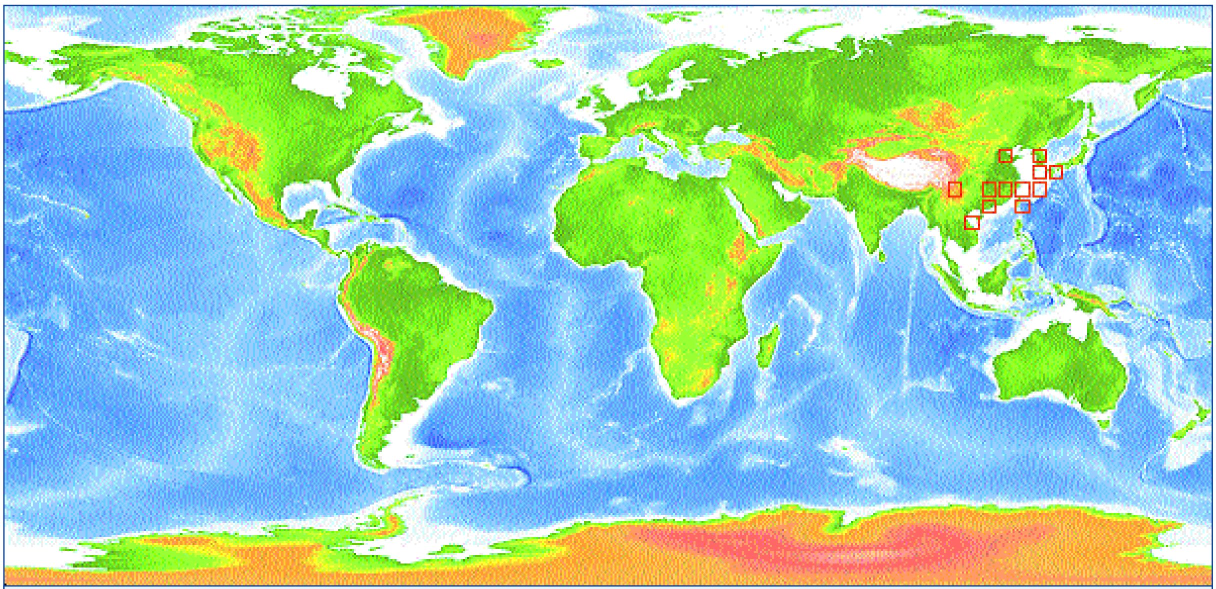


Figure 17. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Anguilla japonica* (FishBase 2002)

Anguilla australis (Richardson, 1841)

Figure 18. Short-fin eel (*Anguilla australis*) (FAO)

Table 6. Characteristics of the Short-fin eel (*Anguilla australis*) (FishBase 2002, modified)

Common name	Short-fin eel.
Size and age	Maximum size of 130 cm TL (male/unsexed) and 106.5 cm TL (female); maximum weight is 7.5 kg; it can survive for a maximum of 32 years (Allen 1989).
Environment	Demersal; freshwater; brackish; marine.
Climate and latitude	Subtropical at 18°S-47°S.

Resilience	Population doubling time is 4.5-14 years with low resilience.
Distribution	Distributed in the South West Pacific: East coast of Australia and New Zealand, extending north to New Caledonia; cited in the West Indian Ocean.
Biology and ecology	Feeds on fish, crustaceans, molluscs, worms, aquatic plants, and terrestrial and aquatic insects. Does not breed outside of its Pacific spawning ground. Migrates to the sea to breed (Armitage *et al.* 1994).
Importance	Commercial fisheries and aquaculture; gamefish.

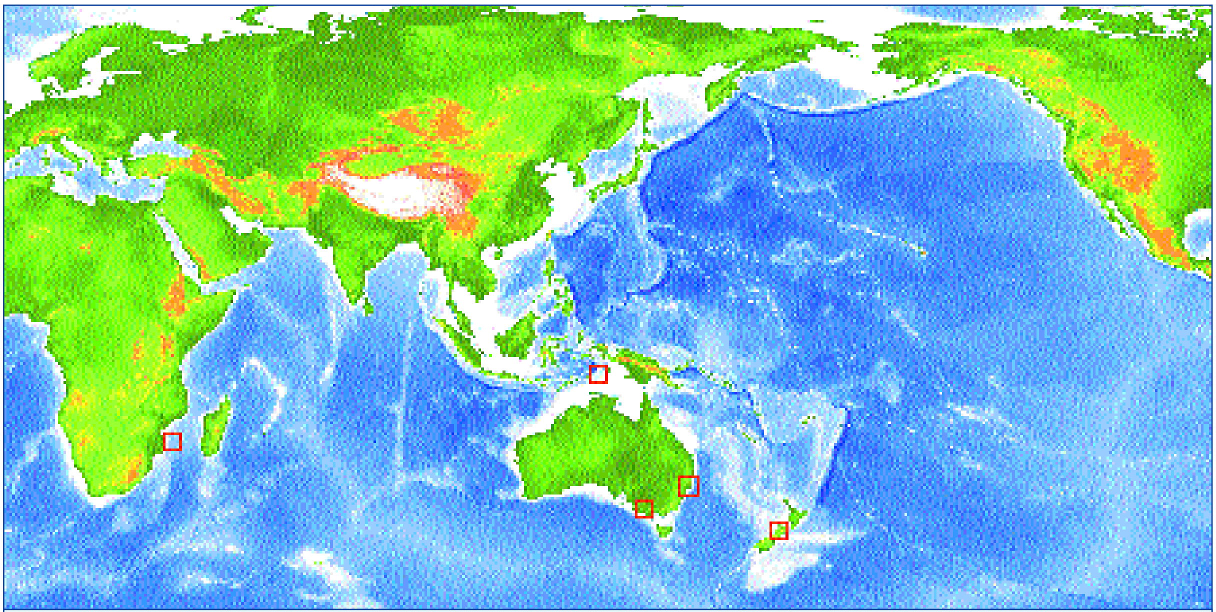


Figure 19. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Anguilla australis* (FishBase 2002)

Fishery trends

Anguilla spp. are found in marine, brackish and fresh waters all around the world, where they are fished constantly because of their accessibility and market demand. The catch (FAO 2002b) is comprized of European eels (*Anguilla anguilla*) in Europe; Japanese eels (*A. japonica*) and "river eels" in general in Asia; European eels in Africa; American eels (*A. rostrata*) in North America; and "river" and short-fin eels (*A. australis*) in Oceania. EIFAC/ICES (2001) term "river eels" as all glass eel and elvers caught for export.

Since 1994 (Figure 20) there has been a global decline in eel catches, from a peak of 18 600 tonnes in 1994 to 12 700 tonnes in 2000. A portion of these figures are glass eels and elvers, so they do not accurately reflect the actual catch.

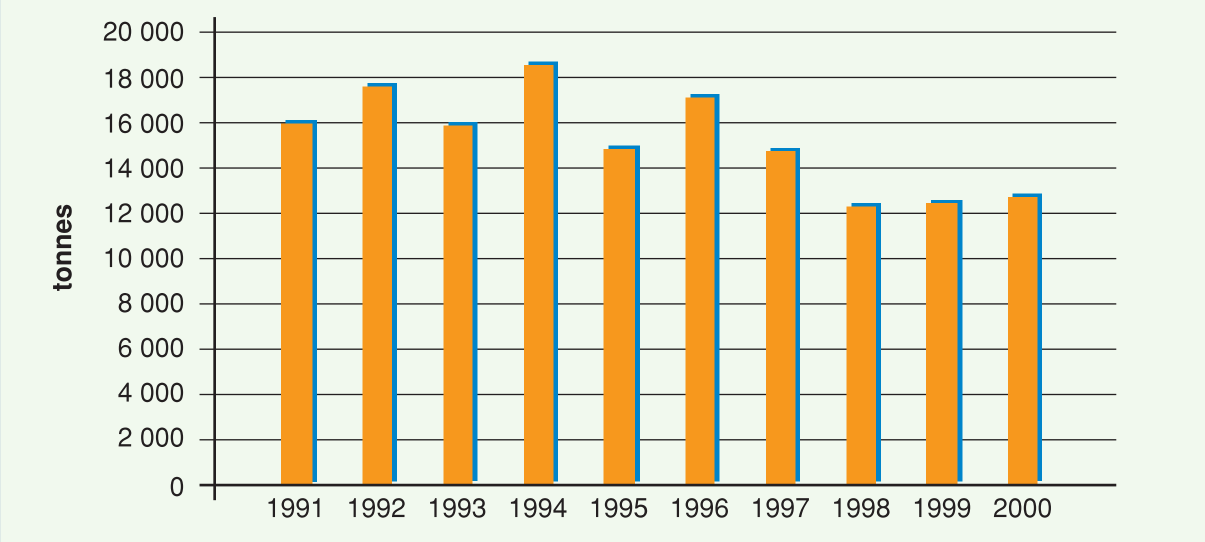


Figure 20. Trends in the global eel catch (1991-2000) (FAO 2002b)

In 1998, the International Council for Exploration of the Sea (ICES) declared the eel spawning stock to be beyond safe biological limits (FAO/ICES/ACFM 1998). In 2000, the global capture totalled 12 700 tonnes, with Europe the leading continent with 5 300 tonnes, followed by Asia (2 400 tonnes), Africa (2 300 tonnes), Oceania (1 600 tonnes) and North America (1 100 tonnes). 77 percent of the catch is from inland waters, with Europe, followed by Africa and Asia, the major areas. The major marine areas where eels are caught are the Northeast Atlantic and the Mediterranean and Black Seas (Figure 21). In 2000 Egypt was the leading country where eels were caught, followed by Indonesia and New Zealand (Figure 22).

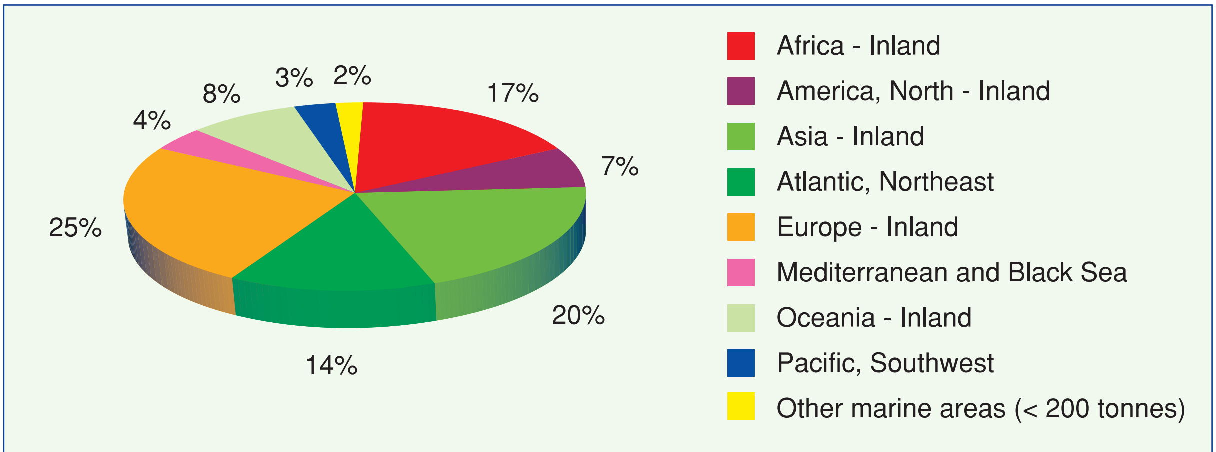


Figure 21. Global eel catch by area in 2000 (FAO 2002b)

In New Zealand, there is a sizeable fishery for both *A. australis* and *A. dieffenbachii*. Although total landings for the decade have averaged around 1 300 tonnes annually, they have declined to an average of about 1 100 tonnes since 1996. The New Zealand fishery has had a quota since 2000 and now the maximum harvest is essentially determined (S. Tibbetts, pers. comm., 2002).

The data from 1991 to 2000 for the European eel (*Anguilla anguilla*) show a marked decline from peak of over 10 000 tonnes; for the last three years of the decade the catch was less than 8 000 tonnes (Figure 23). The European eel catch was spread throughout western Europe and North Africa in 2000 (Table 7). The catch of *Anguilla anguilla* in inland waters totalled over 5 400 tonnes in 2000, with the bulk caught in Europe (57 percent) and Africa (40 percent) (FAO 2002b).

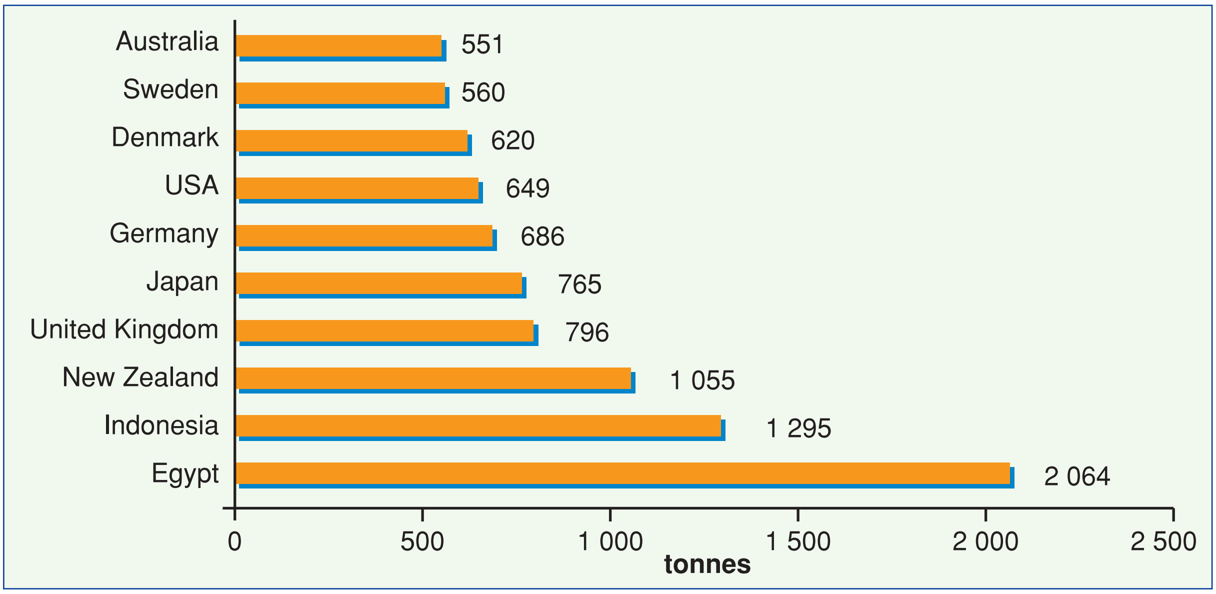


Figure 22. Capture fisheries for eels: the top ten countries in 2000 (FAO 2002b)

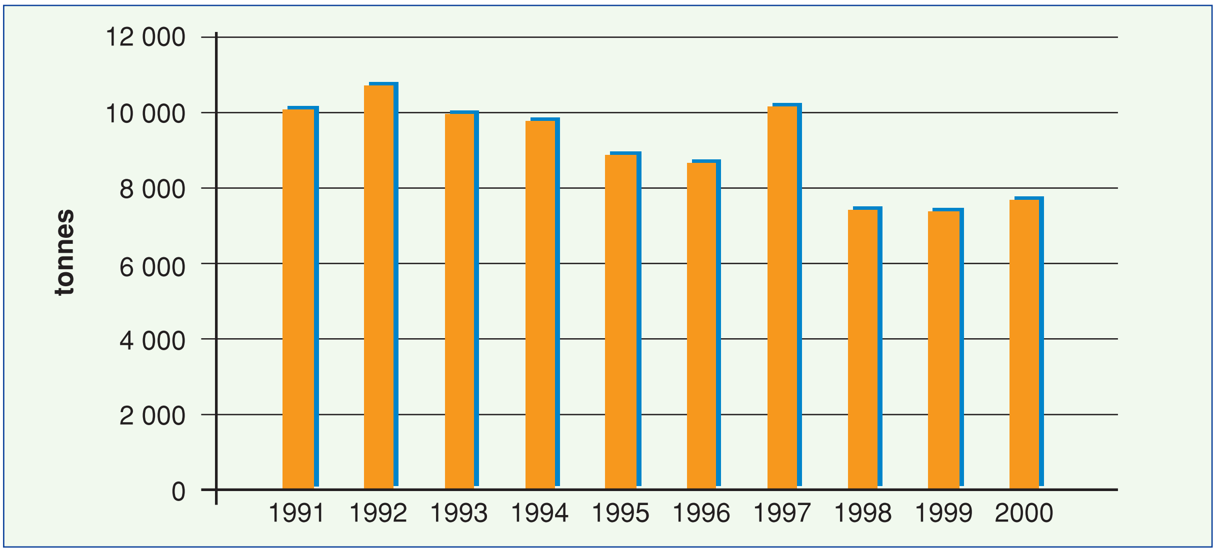


Figure 23. Trends in the global capture fishery for European eels (*Anguilla anguilla*) (FAO 2002b)

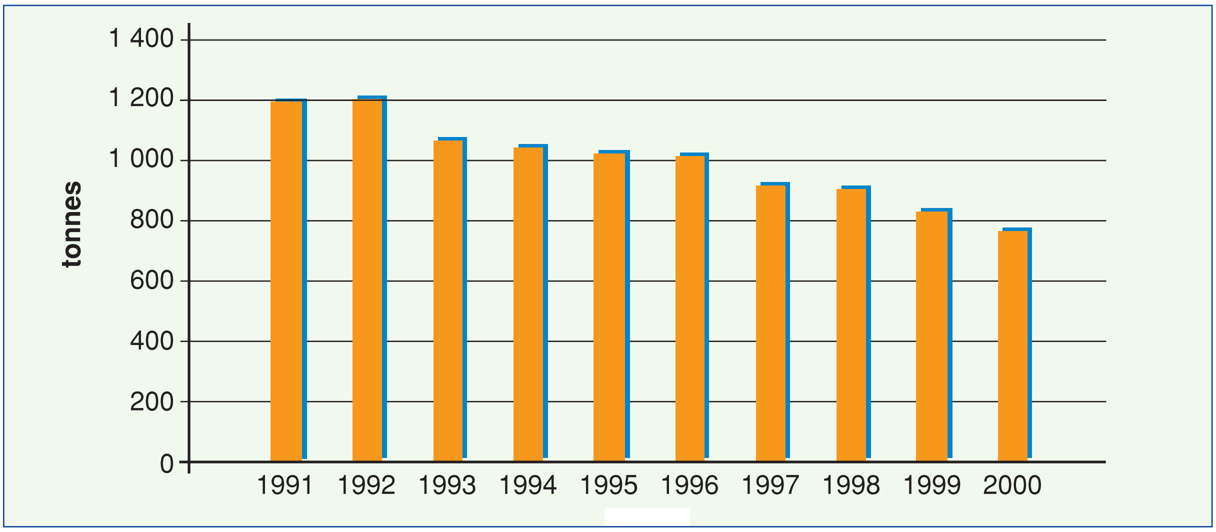


Figure 24. Trends in the global capture fishery for Japanese eels (*Anguilla japonica*) (FAO 2002b)

Table 7. Catch data for European eels (*Anguilla anguilla*) by country in 2000 (FAO 2002b)

Country	European eel catch (tonnes)
Egypt	2 064
United Kingdom	796
Germany	686
Denmark	620
Sweden	560
Italy	549
Poland	429
Netherlands	351
Norway	281
Ireland	250

The global catch of *Anguilla japonica* shows (Figure 24) a similar trend to figures from Europe. In 1990 the total for this species was 1 280 tonnes, distributed between Japan, Korea, Taiwan Province of China and Guam, while in 2000 the total had fallen to 765 tonnes, caught only in Japan.

The American eel is caught only in North America (1 100 tonnes); the catch is mainly from inland waters and in the Northwest Atlantic, with 650 tonnes in the United States and 450 tonnes in Canada. The 2000 catch in Canada was the lowest for 49 years (EIFAC/ICES 2001). In the USA, the American eel fishery area extends from Maine to the Gulf of Mexico. In Canada the fishery areas are in Ontario and Quebec but, in the last two decades, Newfoundland, New Brunswick and Scotia-Fundy have also become important. This species is also captured in Mexico and the Dominican Republic.

The dramatic fall in numbers and volumes over the last decade indicates that all species of eel are under pressure, either from fishing activities or from environmental degradation.

Seed availability for capture-based aquaculture

The life cycle of an eel may take 15-20 years to complete; despite reports that the life cycle of the European eel is expected to be closed soon (Anonymous 2003), artificial propagation of eels has not yet been achieved commercially. Knowledge of the availability of the species in the wild represents one of the hardest problems for fisheries managers (Shepherd and Bromage 1990). This is primarily due to the fact that global eel culture is totally dependent on the availability of wild glass eels and elvers. The international eel market is supplied by Japanese and European glass eels¸ while other eel species form a minor part of the market. Glass eels are the "seed-stock" of choice for Asian and European commercial eel farming, which relies on the combined glass eel fishery for all its "seed". *Anguilla anguilla* in Europe produces 250-1 000 tonnes/year and *A. japonica* in Asia 100-150 tonnes/year.

From the capture-based aquaculture point of view, it is the glass eel stages that are of most interest, while some elvers are produced for further on-growing by producers (Frost *et al.* 2000). The period of time the eels spend at each stage in their life cycle shows considerable variation (Table 8). In all species, the females are larger than the males. Spawning age differs from males to females. For example, females of the American eel spawn at 8-12 years (500 g) whereas males spawn at 6-9 years (150 g) (Tibbetts 2001).

Table 8. The different characteristics of eel stages (Dekker 1999)

Stage	Duration in years*	Mean weight per eel*
Glass eel	0.25	0.3 g
Elver	1-2	8 g
Yellow eel	(4) 6 (20)	200 g
Silver eel	(5) 10 (20)	200 g

* figures in brackets are the shortest and the longest periods recorded

In Europe, the glass eel catch depends on the time that they ascend the rivers. European eels seem to be able to migrate up the rivers at lower temperatures (2-10°C) than Japanese eels. Early migrants are smaller in size (about 7 cm in length) than the later ones (15-20 cm). Glass eels used for farming are collected during the earlier migration, which can vary from autumn to winter. The best catches are generally obtained from February to May.

In Portugal, the first glass eels are caught during October, one month earlier than those in Spain (November and December). In Spain, the catch of glass eel declined from 60 tonnes in 1977 to 6 tonnes in 1997, while in Portugal the annual catch fell from 20 tonnes/year in the period 1976-84 to 5 tonnes in 1997 (Ciccotti, Busilacchi and Cataudella 1999).

The fishing season in France is from November 15th to April 15th, with a special extension on the River Loire to April 20th. There may not be any significant catches until the end of December or the beginning of January. The start of the fishing season is very dependent on weather conditions and varies from year to year. The main catches are made from January to March. The main catching areas are in the Southwest of France, around Bordeaux. There is also a significant fishery in the Loire Valley, close to Nantes (www.glasseel.com). The total French glass eel catch has declined from 1 345 tonnes in 1970 to 578 tonnes in 1995 (Ciccotti, Busilacchi and Cataudella 1999).

In the UK, the principal catching season is from February to April, though some fish are caught as early as January and as late as June. There is no official closed season. The majority of the fishing takes place on the River Severn (www.glasseel.com). The UK Environmental Agency (UKEA 2000) confirms that all life stages of eels are exploited. Glass eel and elver fishing occurs in tidal reaches (the River Severn, the rivers of South-western England and South Wales). Yellow eels are exploited in many areas, although East Anglia is the main centre for this activity. Approximately 10 tonnes of elvers are caught each year while several hundred tonnes of yellow eels are caught.

Danish catches of glass eels are about 500 tonnes/year. The glass eels are used for restocking the commercial fishery, aquaculture (within Europe and for export), and direct consumption (Frost *et al.* 2000).

According to FAO data, the annual catch of the European eel decreased by over 40 percent from 1988 to 1998; only 7 546 tonnes of eels were harvested in 1998 (EIFAC/ICES 1999). The decline of this species is especially worrying since eels are important to many aquatic systems. They are particularly vulnerable due to their long and complex biological cycle, about which much is still unknown. In addition, as many as 25 000 people in rural Asia and Europe depend on the species for their livelihoods (Ringuet and Raymakers 2001). It has therefore become important to manage the European eel with the aim of restoring the stock and avoiding the possible decimation of the European industry. In January 2000, the EC Scientific, Technical and Economic Committee for Fisheries recommended “countries should be encouraged to stop the direct consumption of glass eels and to ban export of glass eels to countries outside the EU” in order to protect the eel stock (STECF 1999).

It has been suggested that changes in ocean currents might be affecting transatlantic migration of leptocephali, which then contribute to the decline in wild populations. The loss of available river habitats, land-based pollution, as well as alien parasitism, all advance the decline of the species. Also, dams are thought to contribute to the decline by limiting the migration of eels (in the “silver eel” stage) back to the sea, and possibly the subsequent reproduction and survival of early larvae; in addition, overfishing is a factor.

Trade plays a major role in the future of eel populations. Towards the end of the 1990s, Japanese eel populations collapsed as a result of the growing demand for the species in the Japanese food market. This contributed greatly to the demand for European glass eels in Asia, thus encouraging overfishing and poaching in Europe, with prices suddenly surging from US$ 88 to US$ 440/kg. In France, which was the first country in Europe to export live glass eels, it was estimated that as much as 80 percent of commercial glass eels came from illegal fishing in the mid-1990s.

At the same time (1988-98), the global aquaculture production of eels doubled from 98 000 tonnes to more than 200 000 tonnes, 95 percent of which was produced in Asian farms. As Europe has increasingly supplied the Asian eel farms with the necessary glass eels, Asia has gradually become more dependent on this form of capture fishery in Europe (Ringuet and Raymakers 2001). Young eels are mostly caught in Western Europe and then exported to eel farms in China, the Republic of Korea and Japan, and then sold and consumed mainly in Japan. From 1996, about 100-200 tonnes/year of European glass eels have gone to Taiwan Province of China, China and Japan (Ciccotti, Busilacchi and Cataudella 1999). In 1997, France exported more than 266 tonnes of European eels to destinations outside the EU (amounting to 55 percent of all EU eel exports outside Europe that year). This represents a vast amount of eels, since 1 tonne of European glass eels can contain as many as 2.5 million individuals. Eels from Western Europe are also used to restock both Central and Northern European rivers and farming facilities (www.traffic.org/dispatches/archives/ march2001/eel.html).

The Japanese eel occurs naturally only in the waters of China, the Republic of Korea, the Democratic People’s Republic of Korea, Japan, and Taiwan Province of China. This form of capture-based aquaculture is totally dependent on natural sources. Therefore, the limited and very unpredictable supply of glass eels is a bottleneck in the further development of eel culture. In Japan itself, glass eels enter the rivers from October through to late May, when the water temperature is 8-10°C. Catches decreased from nearly 58 tonnes in 1990 to 20 tonnes in 1997, a decrease of 65 percent. However, a catch of about 38 tonnes was reported in 1998-99 (Frost *et al.* 2000).

In Taiwan Province of China, the glass eel catching season lasts from October to March (Pillay 1995) and yields between 30 and 150 million individuals, whereas the annual requirements of the local eel farms has been estimated at over 250 million glass eels. Significant increases in local catches are impossible, as the current level of glass eel exploitation in coastal Taiwan Province of China may already be about 45-75 percent of the natural population. The shortage must be made up by imports from the neighbouring countries of the Republic of Korea, the Democratic People's Republic of Korea, and China, which are the main suppliers of glass eels. However, due to the rapid development of a domestic eel culture industry in China, its exports of glass eels are now restricted, and the prospects for the eel culture industry in Taiwan Province of China are now poor (www.american.edu/projects/mandala/TED/eelfarm.htm). The exact level of the glass eel catch in China is not known. Frost *et al.* (2000) reported that 20 tonnes/year are caught domestically, while 120 tonnes are imported.

After the 1970s there has been a general decline in the availability of wild glass eels and elvers. Data collected between 1952-1992 showed that catches peaked in the 1970s and decreased until 1992, when most of the catch consisted only of the early pigmented stages (Lara 1994). Other authors showed that glass-eel production along the coasts of the Atlantic decreased from 1976 to 1984, probably as a result of increased catch per unit effort (Guerrault *et al*. 1986), while pollution seems to be the most important cause of the decrease in elver catches (Wondrak 1985).

Recruitment of the American eel (*Anguilla rostrata*) has also declined dramatically, in parallel to that of the European eel (*A. anguilla*). Since both species spawn in the Sargasso Sea and migrate as larvae to continental waters, this coincidence implies an Atlantic-wide cause, due perhaps to ocean climate. There is indirect evidence that the Gulf Stream weakened in the 1980s. A slower Gulf Stream could interfere with larval transport and generate observed patterns of declining abundance in the American eel and the European eel throughout Europe (Castonguay *et al*. 1994; EIFAC/ICES 2001).

American eel elvers are harvested commercially in Canada, USA, the Caribbean and Central America. In Canada, the commercial fishery began in 1989 in the Scotia-Fundy area (EIFAC/ICES 2001), but catches declined from 4 122 kg in 1997 to 622 kg in 2000. The elver fishery is regulated in this area. The catch of American elvers in the Bay of Fundy, New Brunswick, the Atlantic coast of Nova Scotia and in the State of Maine (EIFAC/ICES 2001) is shown in Table 9.

Yellow and silver eel catches have declined in the St. Lawrence and Ontario region. A series of major habitat modifications in St. Lawrence took place in the 1950 (St. Lawrence Seaway and hydroelectric dams), about 30 year before recruitment started declining; this long delay argues against these being the primary causes for the decline (Castonguay *et al*. 1994).

In the USA, an elver fishery existed in Maine during the late 1970s and collapsed until the 1990s, when Asian demand for elvers for aquaculture greatly increased. Dramatic declines in regional eel populations during the last decade and increasing harvest pressure on all life stages have prompted most north-eastern states to tighten the regulatory control of their fisheries. Minimum size limits of 4-6 inches (10-15 cm) and moratoria on elver collection are in effect until the current status of the eel stocks can be determined. In October 1996, a programme to compile stock assessment data and recommend a regional fishery management plan was initiated by the Atlantic States Marine Fisheries Commission (ASMFC); in November 1999 it approved the first Interstate Fishery Management Plan for the American eel (EIFAC/ICES 2001).

Table 9. Catch of American elvers (*Anguilla rostrata*) (kg) in Canada and Maine (USA) (EIFAC/ICES 2001)

Year	New Brunswick	Nova Scotia	Total Canada	State of Maine
1994	650	924	1 574	3 352
1995	549	2 689	3 238	7 545
1996	449	2 414	2 863	4 633
1997	852	3 270	4 122	3 345
1998	501	1 547	2 048	6 527
1999	0	478	478	1 630
2000	0	622	622	1 630

Asian market demand for American elvers decreased in 1999, due to an increase in naturally available Japanese eel elvers, and the fact that the production of market-sized cultured eels exceeded Asian demand. The result was a reduced fishing effort throughout the area. Several other countries had developed elver fisheries in the 1990s, but no data is currently available (EIFAC/ICES 2001). About 1.25 million pounds (~ 567 000 kg) of eels and elvers were caught in the East Coast of the USA in 1995, the latest annual figures published by the ASMFC (www.ecoscope.com/eelnews.htm). Monitoring of elver catches began in 1998, both in the USA and Canada (EIFAC/ICES 2001).

The periodic reports by FAO of river eel captures in the Caribbean and Cantral America are believed to refer to glass eel/elver catches for export, which were about 49 tonnes/year recently. Incidental records (EIFAC/ICES 2001) refer to 0.4-7 tonnes of glass eels being caught in rivers in Holguin Province, Cuba. Potentially, FAO statistics for this fishery are underestimates; a better recording system for data is urgently needed.

Short-fin eels from the State of New South Wales, Australia have been exported to Europe and Asia for decades but the average annual commercial catch is only 100 tonnes; this is less than 1 percent of the world market for freshwater eels. Since there is a limited knowledge of eel stocks, and in an effort to avoid the problems encountered elsewhere, NSW Fisheries is taking a cautious approach to the harvesting of glass eels and the development of eel aquaculture in this State (Anonymous 1998a,b). Eel aquaculture relies on the availability and sustainability of its seed stock resource. Studies to date suggest a limited availability of glass eel resources in the State of Queensland, although their full extent may take many years to determine. To ensure the available resource is not over exploited, the Queensland Government manages the collection of glass eels, and does not permit their export; heavy penalties apply. Without such controls, the development of a sustainable industry would be severely impaired (www.dpi.qld.gov.au/fishweb/2691.html). Short-fin eels have a winter-spring arrival season in New Zealand, the main months being September-October (D. Jellyman, pers. comm., 2002).

Glass eel supply channels are very complex. In general, the international market is supplied by Japanese and European glass eels, but recently also by American eels at low levels. Worldwide, both legal sales and black markets for glass eels are thriving and there are conflicts between the catch data and market prices, and a general lack of any official data on this market sector, which for eels is the most important.

Japanese and Chinese fishermen catch Japanese glass eels in the waters around Japan. Fights occur between Chinese fishermen wishing to harvest these expensive glass eels, which they call "soft gold". It has been reported that as many as 30 000 fishermen are operating 15 000 vessels to harvest glass eels; these have been obstructing shipping and "sometimes killing each other" in their efforts to harvest eels, which sell for as much as US$ 9 000/lb (over US$ 19 800/kg). The Yangtze River delta reports yields of up to 6 tonnes of glass eels per year (Anonymous 1996). China, being the main producer of eels, also has a big trade in the import and export of glass eels. China exports some glass eels to Taiwan Province of China (via Hong Kong) and Japan, but other producers use their entire catch domestically. Trading of cultured fingerlings occurs from the Democratic People's Republic of Korea, the Republic of Korea and China to Japan, and from Japan to Taiwan Province of China, as well as within each country (Gousset 1992). Chinese statistical records indicate that some 110 000-125 000 kg of glass eels were imported in 2002, with about 70 000 kg via Shanghai and 50 000 kg via Hong Kong (www.glasseel.com).

The surging demand in Asia for fresh seafood and the loss of native eel stocks in Europe are driving a shadowy international market that pays US$ 1 000/kg for "legal" American glass eels air-freighted to Hong Kong, and up to US$ 5 000/kg for shipments of questionable legality (www.ecoscope.com/eelnews.htm). Asian glass eels have sold in Hong Kong for as much as US$ 6 000/kg at times when US$ 1 000 would purchase the same amount of American elvers. It seems that some Hong Kong dealers mix their shipments with the cheaper American eels, and sell the combined batches to mainland Chinese fish farms at the higher price (www.ecoscope.com/ eelnews.htm). Table 10 is an attempt to show the trade routes of elvers of *Anguilla* spp. worldwide, but the overview is incomplete.

Table 10. Some trade routes of *Anguilla* spp. elvers and glass eels

Exporting Country → / Importing Country ↓	SWD	MOR	DK	FR	NL	JP	ES	PHI	NZ	TW	C	KOR	HK	USA	UK
JP				X				X	X	X	X	X	X	X	X
DK				X			X								
TW				X		X					X	X			X
THL										X					
USA													X		
C				X									X		
NL				X			X								
IT	X	X	X	X	X										

Key: C = China; DK = Denmark; ES = Spain; FR = France; HK = Hong Kong;
KOR = Korea (ROK or DPRK not specified); IT = Italy; JP = Japan; MOR = Morocco;
NL = The Netherlands; NZ = New Zealand; PHI = Philippines; SWD = Sweden;
THL = Thailand; TW = Taiwan Province of China; UK = United Kingdom;
USA = United States of America

Capture technology

The capture of all forms of juvenile eels uses a variety of systems, depending on local methods and the position of the catching equipment. A range of sampling methods has been used for studying glass eel recruitment in estuaries and freshwater. These methods include stow nets (McKinnon and Gooley 1998) and fyke nets (Figure 25), plankton nets, flow traps and dip or scoop nets (Silberschneider, Pease and Booth 2001). These methods are expensive because they require continuous monitoring, multiple operators and have to be located in sites with specific physical characteristics. Using bundles of branches (Jellyman and Chisnall 1999) for collecting glass eels is cheaper and easier but, because it uses a wide range of interstitial spaces or too large a mesh size, larger eels can enter and prey on smaller glass eels.

Some glass eel fishing in Spain and Portugal uses hand nets and traps. In Portugal. "Hamen" gears are used (Ciccotti, Busilacchi and Cataudella 1999). Glass eels are caught in France by small trawlers using "wing nets" and "trawls". The only legal fishing gear for this purpose in the UK is the hand net, which has been used for hundreds of years. The number of dip net licences issued for glass eels and elvers is 2 500. Yellow eels are caught with traps (about 1 000 licences) and fyke nets (about 3 700 licences) (UKEA 2000). Glass eels are caught in Northern Ireland with ladder traps for restocking activities (Ciccotti, Busilacchi and Cataudella 1999).

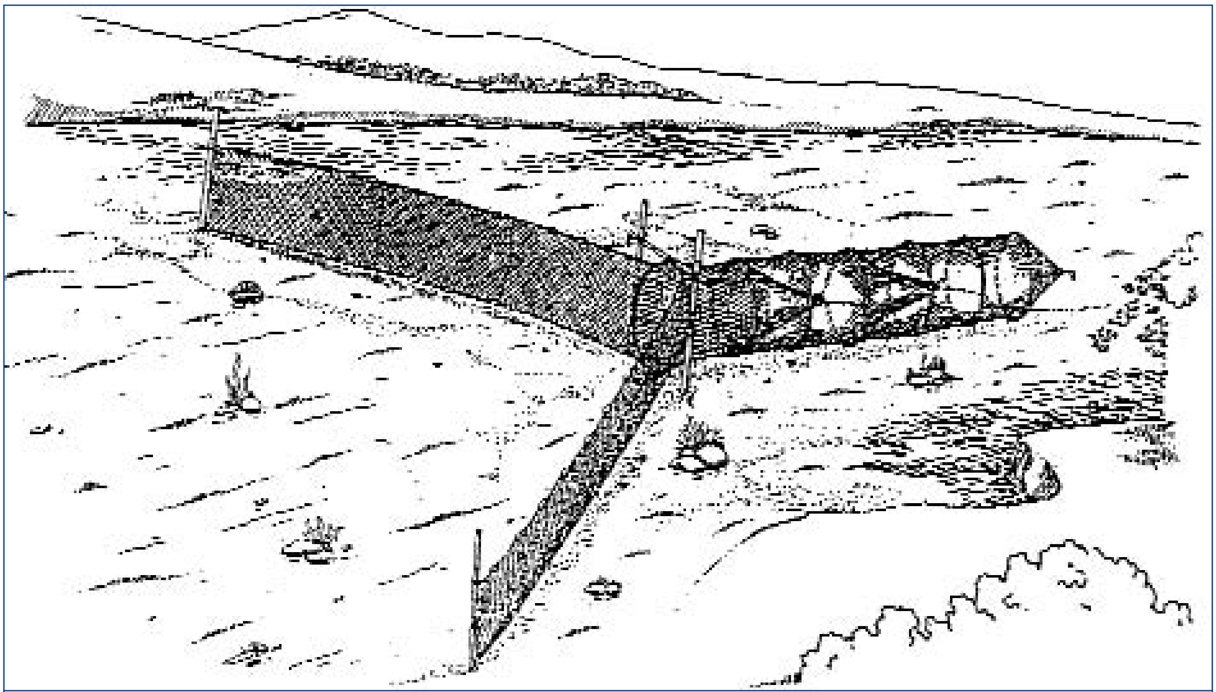


Figure 25. Example of catching method: fyke-net (Source: FAO)

In several Mediterranean countries (Greece, Turkey, Albania, Egypt, Tunisia, Algeria, Morocco and Italy), the juvenile eel fishery has not always been included in legislation, although it is covered by EU Directive 1626/94, under the section for juvenile fisheries for aquaculture and restocking (Ciccotti, Busilacchi and Cataudella 1999).

The fisheries for European eels (*Anguilla anguilla*) have seen dramatic declines during the 1970s and 1980s, which has tentatively been attributed to the unrestricted increase in fishing effort (eel boxes, fyke nets and gill nets). Until the mid-1980s no measures were taken to determine and/or restrict the fishing effort. However, from 1985 the number of fyke nets was fixed; other gears were left unrestricted (Dekker 1991).

Silberschneider, Pease and Booth (2001) described a new glass eel collection system, which is based on special collectors that "attract glass eels by mimicking the complex natural habitat that glass eels seek in the wild". These collectors exploit surface roughness, protective tufts and other characteristics that are similar to the sea-grass beds that attract wild glass eels in the proximity of estuaries. This method is inexpensive, requires low maintenance, and provides a relative abundance of resettling glass eels.

In Japan elvers are attracted by bright lights, and are then caught in scoop nets at night, or fine-meshed bag nets set across the river. Special elver traps may also be set near obstructions in the rivers, where the elvers are likely to congregate. In Taiwan Province of China, the elvers are caught with scoop nets, drag nets or eel traps (Figure 26) (Pillay 1995).

Short-fin glass eels and elvers are caught from the wild for stocking in culture facilities in North America (north of Mexico), using fine mesh fyke nets and dip nets (Page and Burr 1991). Licences are required, and the quantity allowed to be caught is related to the size of the production facilities.

American silver eels and yellow eels are captured with bottom trawls, electro-fishing, large commercial weir (interception) nets, pot fisheries and beach seines; all other gears are banned (EIFAC/ICES 2001). In the USA, legislation controls and licenses the fishery for eels, and includes gear fees and harvest locality limitations that vary from State to State. All the Atlantic States, with the exception of Florida and South Carolina, have responded to warnings and have cracked down on “eeling”. New Jersey has banned the use of fixed nets and creels and, from 2002, only allows fishermen to use handheld dip nets from February 15 to April 20. There is a legal eel fishery in South Carolina for residents only, with fyke and dip nets. The State’s glass eel season typically runs from January to March and harvest areas are limited. In Maine, glass eels are also caught with fyke or dip nets, with a limit of 5 fyke nets. The catching season runs from March 15 till June 15 (www.ecoscope.com/eelnews.htm).

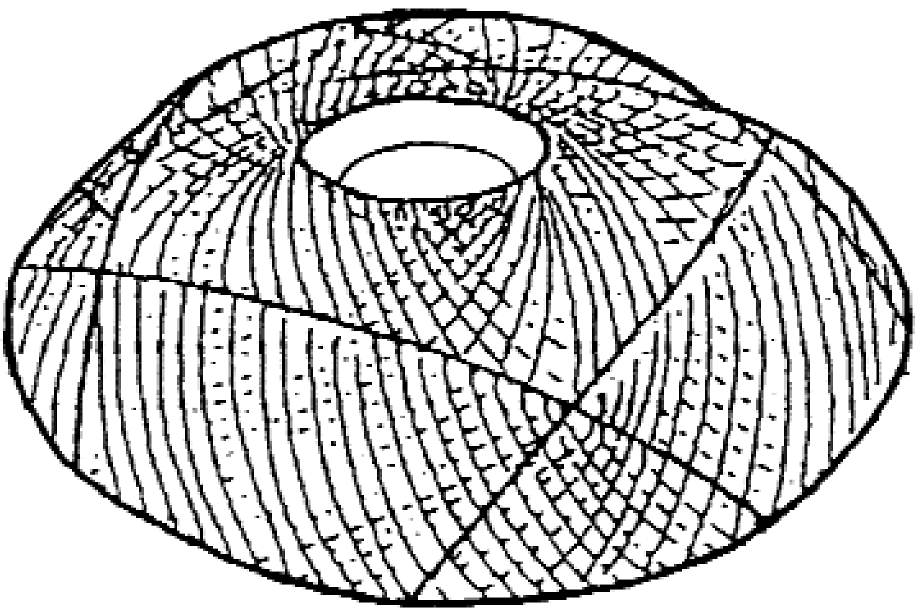


Figure 26. Example of catching method: fish trap (Source: FAO)

Transfer of "seed" material from fishing to on-growing facilities

Glass eels are very valuable and also very delicate. The method of capture should be as "passive" as possible to limit damage and to minimize the losses that occur between the fishery and the capture-based aquaculture facilities. Trawling compresses the glass eels with small fish and detritus. Their integrity becomes damaged, and osmoregulation and defence mechanisms are compromized. In France, mortalities during catching, handling and transport from its great estuaries are more than 20 percent (Ciccotti, Busilacchi and Cataudella 1999).

Initially the glass eels appear to be normal, especially when stored in salt water. Following further handling and transportation, after a few days storage on the farm, it is common to notice that the glass eels start to swell and become opaque; death follows quickly. Good management, increasing the temperature to 25-28°C and, in some cases antibiotic treatment, can help to reduce mortalities during transport, but starting with good quality glass eels is the best solution (www.glasseel.com).

Methods for transferring captured eels from the capture area to farms are more or less standardized worldwide. Transport ashore is made in aerated tanks for European eels, and in wooden boxes (after a day in tanks or bamboo baskets) for Japanese eels. Elvers of European eels are transported to on-growing facilities in polyethylene bags at the temperature of 4-7°C (Pillay 1995).

American eel (*A. rostrata*) elvers are sensitive to low oxygen levels (Facey and Van Den Avyle 1986) and require 11 ppm DO_2 for their transport to farming facilities (Sheldon 1974).

Trends in aquaculture production

Global eel aquaculture has shown an increasing trend from 1991 to 2000; rising from about 185 000 tonnes in 1991 to levels of about 230 000 tonnes since 1996 (Figure 27). Global demand for eels is estimated at about 200 000 tonnes/year (Frost *et al.* 2000).

Production is predominantly based on the culture of the European eel (*Anguilla anguilla*) in Europe, Japan and China, and the Japanese eel (*A. japonica*) in China, Taiwan Province of China and Japan. Most of the global increase in production has been seen in China, which is now the major producer. This has been due to the increasing intensification of farming systems and the diversification from *A. japonica* to *A. anguilla*. There are a number of reasons for this shift. Firstly, Japanese glass eels have been undersupplied. Secondly, European glass eels have a price advantage. Thirdly, Chinese eel farmers have gradually developed better farming methods for European eels, which make it possible to raise them on a larger scale. In 1998, China was reported to have produced 50 000 tonnes of European eels (Frost *et al.* 2000) but this is not specifically recorded in FAO statistics (FAO 2002a); the whole of Chinese production is recorded as *A. japonica*. Recently there has also been some culture of *Anguilla rostrata* in Asia. It is estimated that production is between 3 000 and 5 000 tonnes (www.glasseel.com).

There has also been an increase in the production of *A. anguilla* by farms in the Netherlands and Denmark, which appears to have occurred as a result of increased marked demand from Japan and the introduction of more intensive production techniques, including the use of commercially available re-circulating aquaculture systems. However, the production of short-fin eels (*A. australis*) is still small in Australia and New Zealand.

The combined effect of the introduction of new species to traditional eel culture locations and systems intensification has substantially increased the production and value of the global eel aquaculture industry over the last decade.

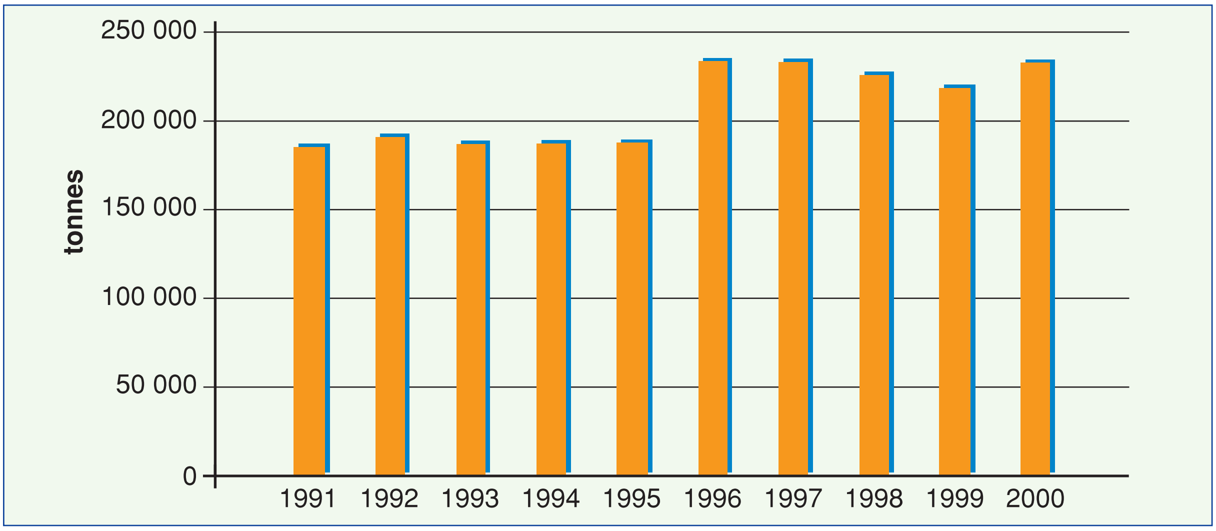


Figure 27. Trends in global eel production by aquaculture (FAO 2002a)

Asia was the major continental producer in 2000, with 222 000 tonnes, accounting for 95 percent of total eel production. Europe followed with 10 600 tonnes, Africa (73 tonnes) and Oceania (26 tonnes) were minor producers. 220 000 tonnes of Japanese eel (*A. japonica*) and 2 000 tonnes of "river eel" were produced in Asia, while European and African production consisted entirely of the European eel (*A. anguilla*). In Oceania, the data refers to short-fin eels (*A. australis*). FAO statistics are regarded as underestimates, since they do not include the production of European eels in China: in 1998, China produced 50 000 tonnes of European eels (Frost *et al.* 2000).

Global production in freshwater reached 228 000 tonnes in 2000, consisting of 217 709 tonnes of Japanese eels and 326 tonnes of river eels in Asia, followed by nearly 9 986 tonnes in Europe (all European eels) and 20 tonnes in Africa. In brackish waters, production was nearly 4 500 tonnes: about 4 064 in Asia (57 percent Japanese eels), 321 tonnes in Europe, 53 tonnes in Africa and 26 tonnes in Oceania. Maricultured eel production is present only in Europe (310 tonnes).

Single species data shows that Japanese eel production rose from 178 000 tonnes in 1991 to peaks of 223 000 tonnes in 1997 and 220 000 tonnes in 2000 (Figure 28). This species is produced only in Asia, both in brackish and freshwaters, where the production was 2 300 tonnes and 217 700 tonnes, respectively.

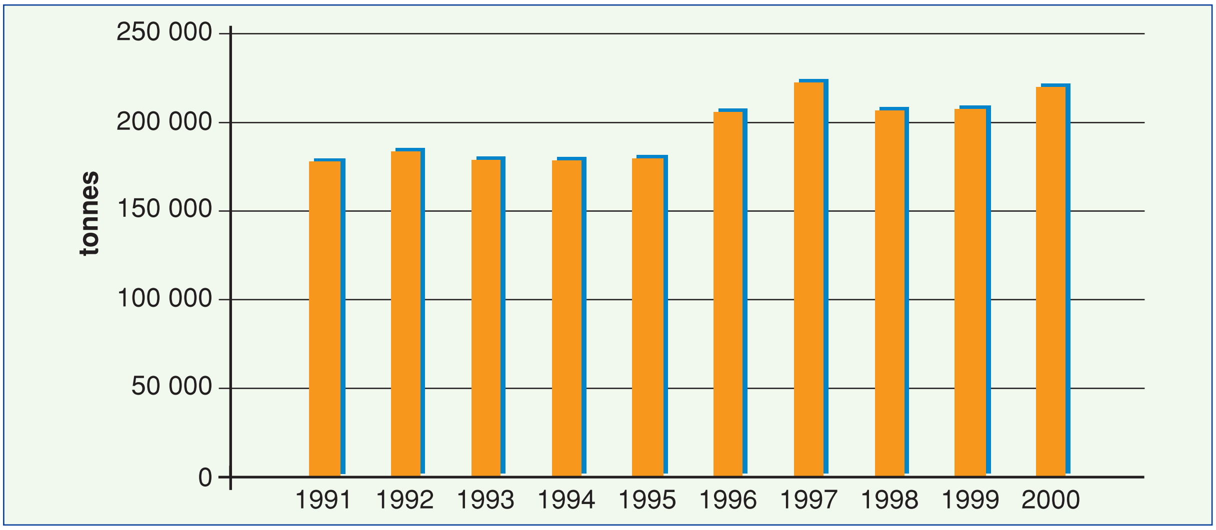


Figure 28. Global trends in the production of Japanese eels (*Anguilla japonica*) through aquaculture (FAO 2002a)

Table 11 shows the main producing countries for Japanese eels. Japan is also an important eel market, consuming more than 100 000 tonnes in 1996 (www.ecoscope.com/ eelbase).

Table 11. Japanese eel (*Anguilla japonica*) production by country (2000) (FAO 2002a)

Country	(tonnes)
China	160 740
Taiwan Province of China	30 480
Japan	24 118
Korea, Republic of	2 725
Malaysia	1 980
TOTAL	**220 043**

In Japan, eel farms are located mainly in Aichi, Kagoshima and Shizuoka, followed by other prefectures such as Miyazaki, Kochi, Tokushima and Mie. There has been a significant decline in the number of eel farmers, due to several reasons: aging of farmers and a shortage of successors, a dramatic decline in wild eel numbers, competition from imports, and rising costs for elvers and farm production. The number of eel farmers in Japan peaked in 1973 (3 250), but fell by 80 percent to 651 households in 1997. Total yield in Japan, including both wild and farmed eels, peaked at 41 094 tonnes in 1985. Yields over the past five years are shown in Table 12 (www.wtco.osakawtc.or.jp/e/market/item/eels.html). In 1998, 96 percent of the eels produced in Japan were farmed.

Table 12. Total yield of wild and farmed eels in Japan

	Yield (tonnes)
1994	29 431
1995	29 131
1996	28 616
1997	25 031
1998	22 845

In Thailand, Thai Unagi Co Ltd started an eel farm in Chacheongsao in 2000 which is expected to raise an annual total of 10 000 glass eels (*Anguilla japonica*) imported from Taiwan Province of China. Domestic consumption of eels in Thailand totals about 300 tonnes/year, of which the company supplies 20 tonnes, with the rest imported as roasted eels ("*kabayaki*") from Taiwan Province of China and Japan.

China imports glass eels from Europe. The quantity required by China is falling to a more manageable level, and there were some significant problems for eel farmers in 2002 (www.glasseel.com). Firstly, there was an European ban on imports of Chinese agricultural products of animal origin because of the presence of medicinal residues. Secondly, Japan, the main consumer of eels, was also becoming conscious of the residue problem. In 2002 six "*kabayaki*" processing factories in Fujian are unable to export to Japan. New testing protocols for live imports into Japan are causing considerable delays, making it virtually impossible to export live eels from China to that country.

These events stimulated the demand for eels from Taiwan Province of China, where residue testing for veterinary medicines has been practized for a number of years. In spite of all these problems, ex-farm prices of eels in China in 2002 for size 3 pieces increased from € 1.54/kg in January to € 5.50/kg at the start of April, peaking at € 6.80/kg - the breakeven production price is € 4.80/kg. These prices could reflect a market situation where there is an overall shortage of eel stocks in China. For a short time in May 2002, *Anguilla japonica* eels (250-500 g) reached € 18.8 each (www.glasseel.com). There were 12 indoor re-circulating water production systems for eels In Taiwan Province of China, in 1999 (Table 13).

Table 13. Indoor eel re-circulating systems in Taiwan Province of China in 1999
(Source: www.aquafind.com/articles/Taiwan.com)

Farm	Capacity (tonnes)	Location	Year of construction
1	5	Keelung	1993
2	100	Tainan	1995
3	172	Tainan	1995
4	105	Taoyuan	1995
5	20	Taoyuan	1995
6	370	Taoyuan	1995
7	150	Ilan	1996
8	50	Tainan	1997
9	500	Hualian	1997
10	120	Taipei	1998
11	400	Tainan	1998
12	50	Taoyuan	1999

European eel production also increased in the decade to 2000. 6 700 tonnes were produced in 1991 and 10 700 tonnes in 2000 (Figure 29) in Europe. FAO data refers only to European production and does not include production in China; China produced 50 000 tonnes of European eels in 1998 (live weight), corresponding to 30 000 tonnes of "*kabayaki*" (Frost *et al.* 2000). European eels are cultured in Europe, Asia, and marginally in Africa, in all environments (brackish water, mariculture, freshwater). The bulk of production in 2000 came from inland waters in Europe, together with about 300 tonnes each from the Northeast Atlantic and the Mediterranean and Black Sea. The leading producer (Figure 30) was the Netherlands (3 700 tonnes), followed by Italy and Denmark (each around 2 700 tonnes).

The capture-based aquaculture of eels is an expanding activity, particularly in the Netherlands and Denmark. Production depends on the availability of glass eels imported from France, Spain and England. In Denmark, it has been calculated that from of a single metric ton of glass eels an eel farm can produce about 200 tonnes (Frost *et al.* 2000).

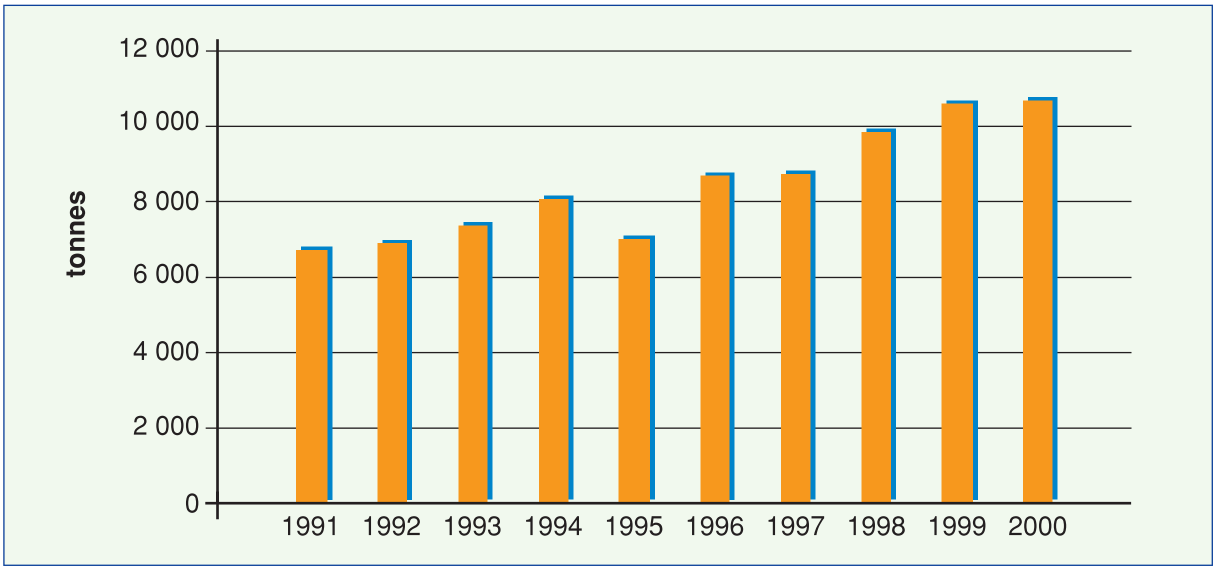


Figure 29. Farmed production of European eels (*Anguilla anguilla*) in Europe (FAO 2002a)

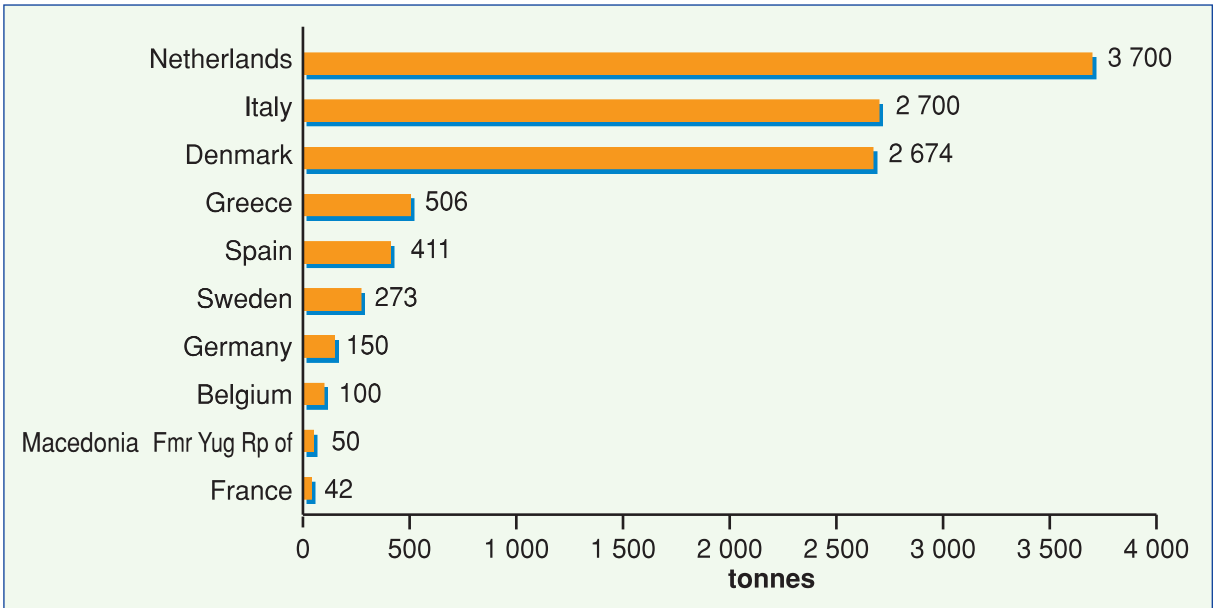


Figure 30. Top ten farmed European eels (*Anguilla anguilla*) producers in Europe in 2000 (FAO 2002a)

There were 11 eel farms in operation in Greece in 2000, with an annual production of 500 tonnes. Lack of processing facilities, disorganized marketing and, mainly, the lack of quality glass eels or elvers for on-growing have led to relatively low levels of production. The eel farms are small units producing on average 50 tonnes per year with only four farms operating re-circulated water systems.

There is one large company in Valencia, Spain that produces about 300 tonnes/year in re-circulation systems. In the Delta del Ebro region there are two producers in open systems (one of them produces 60 tonnes/year), and another in the Basque country using a re-circulation system (60 tonnes/year) (L.P. Igualada, pers. comm. 2002).

Total production of European eels from brackish waters in 2000 was 374 tonnes, with Italy as leading country (250 tonnes), followed by Greece (56 tonnes) and Morocco (35 tonnes). In mariculture, Spain was the main producer (302 tonnes). The only other producer was Greece (8 tonnes). In freshwater the Netherlands was the leader (3 700 tonnes), followed by Denmark and Italy (2 674 and 2 450 tonnes respectively). Intensive eel production in Europe is shown in table 14.

Table 14. Intensive eel production in Europe in 1998 and 2000 (Frost *et al.* 2000, modified)

Country	Number of farms		Production (tonnes)	
	1998	2000	1998	2000
Netherlands	55	60	3 000	3 700
Italy	74		3 100	2 700
Denmark	28	60	2 500	2 700
Greece	9	11	500	500
Ireland	1		100	
Belgium	3		160	100
Luxembourg	1		50	
Spain	2	4	340	411
Sweden	3		230	273
Germany	5		300	150

Total production of *A. australis* in Australia is presently in the order of 500-700 tonnes/year, worth A$ 4.0-7.5 million (www.fisheries.nsw.gov.au/aquaculture/freshwater/eels.htm), the vast majority of which comes from capture fisheries, which historically have been from stock enhanced wild fisheries (also referred to by the industry as “cultured eels”). Further expansion of the industry is presently constrained by the limited application of intensive production techniques and limited access to local glass eel supplies. While a significant commercial fishery exists (both from dams/impoundments and estuaries), and huge export markets are available, the eel farming industry in New South Wales (NSW) is still small. There are over 20 licensed eel farms there but the total production was only 2.4 tonnes for both short-fin and long-fin eel species for the 1999/2000 production year.

In New Zealand, there are no eel farms that operate on a commercial scale. It is illegal to exploit (for commercial purposes) any eel smaller than 220 g (which excludes glass eels). Most of the experimental work is aimed at increasing weight and fat content of yellow eels (200 g grown to 300-400 g) in about 5 farms, while another 5 companies and research organizations are looking at the possibilities of growing on glass eels (0.2 g each), but there will be legal problems in expanding this to a commercial scale (S. Tibbetts and D. Jellyman, pers. comm. 2002).

Culture systems

Eel farming around the world employs a variety of reliable, well established systems from relatively low-density (<5-10 kg/m^3) flow-through pond culture under ambient conditions, semi-intensive (10-100 kg/m^3) pond and tank culture under semi-controlled conditions, to super high-density (>100 kg/m^3) in closed loop (re-circulation) tank culture in a completely controlled environment. Culture tanks and ponds vary in size from small nursery tanks (e.g. 1-10 m^3 capacity) to large grow-out ponds (e.g. 0.05-0.2 ha surface area). Water supplies for culture systems also vary from fresh to brackish, and from the use of surface waters at ambient temperatures to heated industrial effluent and geothermal artesian aquifers.

Traditionally, in Europe freshwater eels are cultured in ponds and are generally stocked at 100-350/m². When they reach marketable size they are transferred to larger ponds (1 000-1 500 m²). Water can be still or running, though the latter is preferred for intensive stocking and high production (Pillay 1995). According to Shepherd and Bromage (1990) the optimal temperature of 18-25°C is achievable for an average of 250 days every year, making it a very good location for eel culture. European eels grow slowly, even under the optimal conditions of 22-24°C, as cited by Grandi *et al.* (2000); at these temperatures, and feeding *ad libitum*, the rearing of elvers to a market size requires more than 2 years.

Indoor systems, where the culture water is treated and re-circulated, are a special development of the land-based intensive culture system. The development started in the 1950s in Japan and, experimentally, in Europe in the 1970s. Commercial utilization started in northern Europe, mainly in the Netherlands, Denmark and Germany in the early 1980s. Instead of being released, the waste water is recycled after mechanical and biological filtration and oxygen injection. Most eel farming in Europe, apart from the traditional forms of eel culture in Italy, is done in re-circulating systems where a combination of good water quality, appropriate temperature and oxygenation can allow stocking densities of more than 50 kg/m³ (i.e. 5 percent of the volume consists of eels) without compromising the health or welfare of the fish. In the Netherlands, eels are farmed in re-circulating systems at 23-26°C (Eding and Kamstra 2001).

All fish emit waste products after metabolism of their feed; ammonia is the most important toxic waste. With a better feed utilization by the eels, waste production can be minimized. The trend is that environmental rules are forcing re-circulation eel farms to reuse a higher percentage of water, thereby minimising the amount of discharge water, especially in Denmark and Holland (www.danafeed.dk/upl/doc/3.doc).

Eels are also cultured in marine and brackish waters. In the Mediterranean lagoons, or "*valli*", *Anguilla anguilla* elvers enter with tidal flows into "*lavorieri*" traps. In this rich environment, with large quantities of organic food available, they grow very rapidly. In these environments, when oxygen concentration and pH are low, the system can produce hydrogen sulphide, which is toxic for animals and can cause negative impacts on the aquaculture system. The advantages of this type of culture include a reduction in pond construction and water supply costs; some culture centres are located close to thermal stations where the water is warmer and eels grow better than in colder waters. In "*valli*", mainly in the North Adriatic, elvers of 15-35 g are grown at stocking densities of 4 to 15 kg/ha. These elvers are imported mainly from France; in 1999 the cost was € 1,000/kg. About 300 tonnes of elvers are imported each year, but in 1995 about 100 tonnes (50-100 g each) were also imported from Denmark, as there was a reduced supply from France (200 tonnes). For this reason, many Italian eel farmers have imported elvers from Denmark, Holland and Sweden (10 g weaned in re-circulating systems) since 1992 (Ciccotti, Busilacchi and Cataudella 1999).

A wide range of culture methods have been investigated by Japanese eel farmers; from outdoor ponds to closed systems, and from seawater to freshwater culture techniques. From these, four methods are currently used, which can be categorized by their main features: outdoor ponds, basic greenhouse ponds, ponds with a sedimentation unit, and ponds with a bio-filtration unit. Japanese eel farms are usually small (20 to 40 tonnes annual production). They are mainly located in Aichi, Shizuoka, Kochi and Kagoshima Prefectures, and most of them are supplied with water from boreholes. 120 tonnes of glass eels are required every year to satisfy the needs of these producers, whilst annual wild catches fluctuate from 50 to 140 tonnes. Farmers stock Japanese eels (*Anguilla japonica*) at high densities (500-600 g/m²); elvers are stocked in ponds (165 m², 40 cm depth) where they are on-grown before being transferred to ponds of about 200 m² surface area, at lower densities. Eels are mostly stocked in warm water ponds which have an average water temperature of 25°C throughout the year. Heating systems may be used for cold periods during the winter months. However, owing to the cold climate, Japanese eel farms have shifted from outdoor ponds to greenhouse ponds, in order to shorten the rearing period (Kobayashi, Shiino and Miyazaki 1999).

In Taiwan Province of China, eel farming is at the top of the fishery industry in terms of export value. The first experimental eel farm was established in 1952. Small-scale commercial eel farming on the island began in 1958 and the first large-scale expansion of eel farming took place in 1964, in the form of a nursery operation, raising glass eels to stocking size fingerlings for Japanese eel farms. Throughout the history of eel farming in Taiwan Province of China, the industry has mainly been developed for exploiting the market in Japan; the first exports of market-size eels to Japan began in 1970. In 30 years, eel farming has developed into one of the largest sectors of the aquaculture industry on the island. Japanese eels are a high-value product and suitable for intensive pond culture. Japanese eel (*Anguilla japonica*) ponds in Taiwan Province of China are all located outdoors and have earth bottoms. These ponds can be divided into two types: "hard ponds" (with concrete, stone or brick dikes) and "soft ponds" (with earth dikes). Hard ponds are mainly used to culture elvers to market size, while soft ponds are used for juveniles and have lower production costs. The technology for eel culture in Taiwan Province of China is well established and has reached a high degree of specialization. In recent years, *A. japonica* is the only species cultured in Taiwan Province of China due to performance, temperature preferences and the serious disease problems encountered with other species. Its main export market is Japan, which is the destination of 90 percent of its eel exports (Wu 1999).

The capture-based aquaculture of eels in China is traditionally based, scale-dependent, low-tech and natural resource consuming. Both European and Japanese eels are cultured in earth pond systems, usually for the commoner or cheaper animals and products. A small percentage of production is from land-based tank systems and net-cage systems (placed in lakes and reservoirs) but, since these systems have higher investment costs, they are used only for those fetching higher prices (Mai and Tan 2000).

Japanese eels are farmed in Thailand in freshwater ponds. Its warm climate is suitable for raising eels, shortening the growth period. The offspring grow from a length of 4 cm to a weight between 250 and 500 g in five to six months.

Most of the research in Australia has focused on pond production. Short-fin eels grow rapidly in a tropical climate, preferring temperatures between 23-28°C. It has been suggested that the northern coast of NSW could provide the ideal climate, while temperature-controlled intensive tank systems could possibly be located anywhere. In these ideal conditions short-fin eels grow to marketable size (150 to 200g) in 12 to 18 months and 200-300g in 18-24 months. Growth in extensive pond systems is usually much slower. Eel farming also requires access to large volumes of water, due to the very high stocking densities and messy feeding behaviour of the eels; regular water exchange is usually a necessity. For the intensive pond culture of eels, NSW Fisheries recommends a water budget of at least 60 million litres/ha/year (www.fisheries.nsw.gov.au/aquaculture/freshwater/eels.htm).

The best sites for the pond-based culture of short-fin eels are those with a constant water supply and which are not susceptible to flooding. Borehole water is suitable as long as it is free from pathogens, chemical residues and has a pH of 7.0 to 8.0. Highly acidic water is not acceptable and dissolved oxygen levels should be no lower than 3 mg/l. Free ammonia levels should be less than 0.2 mg/l. A gently sloping site is advantageous, to maximize the use of gravity for filling and draining ponds. Stocking rates in tank systems and intensive pond systems vary, depending on the capacity of the system and the intensity of the operation. In well-developed tank systems, stocking rates can exceed 80 kg/m^3, while in super intensive pond systems, they can exceed 20 tonnes/ha. Short-fin eels will usually tolerate conditions worse than those specified, for very short periods. However, this will stress the fish and leave them susceptible to various bacterial, fungal and viral infections, leading to higher mortality rates and possible transmission of infection to other ponds.

For intensive tank-based eel aquaculture, site selection criteria are less restrictive, although a source of good quality water is still essential. Choosing a potential site for tank culture is generally easier because less land area is required and the volumes of intake water are lower. Factors such as topography, soil quality and climate are not so much of an issue. A basic intensive re-circulation system should consist of a number of tanks (usually 1-13 tonnes), either independent or in groups, filtered by mechanical and bio-filters, which are used to strip nitrogenous waste and nutrients from the water. Re-circulation systems can also incorporate a number of other units including UV and ozonation systems to disinfect water and protein skimmers to remove protein based wastes, etc. After passing through the filters, the water is recycled back to the tanks. The entire system should be contained within a vermin-proof, climate-controlled housing. Specialized technical advice should be sought to determine the best set-up (www.fisheries.nsw.gov.au/aquaculture/freshwater/eels.htm). There are many companies throughout the world that are capable of providing consultancy and equipment for these intensive re-circulation systems.

Feeds and feeding regimes

Formulated eel diets are in use in many farms (Pillay 1995). Almost all forms of intensive eel farming now rely on artificial feed, that is high-energy, protein-rich, compound diets in the form of a moist paste for glass eels, and steam-pressed or extruded pellets for later developmental stages. Starter feeding for glass eels is considered the most difficult component of the rearing of eels. The non-acceptance of artificial feed can lead to mortalities and retarded growth. Elver feeding starts when the water temperature reaches about 15°C. The ideal temperature range for eels to remain healthy and to convert feed efficiently is 23-28°C. Temperatures above optimal result in reduced feeding and growth rates, stress and sometimes death. Temperatures below optimal result in decreased metabolism and growth. Small aquatic worms (*Tubifex* sp.) are considered a suitable first feed for elvers and, after two or three days, fish flesh is added in progressively increasing quantities until about the tenth day, when only a paste of minced fish is given (www.fisheries.nsw.gov.au/aquaculture/freshwater/eels.htm). Sometimes brine shrimp is used in conjunction with worms and minced fish to wean Australian glass eels onto artificial foods. Eels should be quickly weaned from the time they enter the farm. A range of commercial fish pellets are available in Australia that are suitable for short and long-fin eels. They are fed several times per day, which ensures that they are healthy, and grow rapidly. Artificial pastes and pelleted diets imported from Taiwan Province of China have also proved suitable and these products are now being formulated and manufactured in Australia for short-fin eels (www.rirdc.gov.au/pub/ handbook/eels.html).

Eels are naturally aggressive, highly carnivorous, top-order predators with a relatively large mouth. In high-density aquaculture, grading (usually every 4-8 weeks) minimizes the risk of cannibalism and encourages efficient feeding behaviour and food conversion. Eels are nocturnal feeders, so the feeding spot is usually covered with boards or other suitable materials, to make it as dark as possible. Food conversion ratios (FCRs) for Asian and European intensive-culture systems vary between 0.9:1 and 1.9:1. Industry standard FCRs have yet to be determined for

Australian eel culture systems, but it is expected that they will vary with species, size, system design, food type, water temperature and quality (www.fisheries.nsw.gov.au/aquaculture/freshwater/eels.htm). The recommended protein level in practical diets for elvers is 50-60 percent, and 40-45 percent for sub-adults (Pillay 1995).

Taiwan Province of China produces a large amount of aquafeeds for eels. Table 15 shows data from Taiwan Province of China and Korea.

Table 15. Production of artificial eel feeds (tonnes) in the Republic of Korea and Taiwan Province of China (www.aquafeed.com/asia/pickup.html)

Country	1997	1998	1999
Republic of Korea	12 000	7 000	6 000
Taiwan Province of China	78 000	50 000	35 000

Fish cultured in earth pond systems in China, such as eels, are directly fed with raw ingredients, such as rice bran, wheat bran, rapeseed meal, peanut meal and soybean meal. 70 percent of the formulated aquafeeds annually produced in China are used in pond culture, with the balance being used in netcage and land-based tank systems. Extensive studies to develop artificial feeds started in the 1980s as the market demand increased; the freshwater species studied included Japanese eels. By 1999 there were several hundred aquafeed manufacturers in China (Mai and Tan 2000). One company producing special feeds for eels is the Zhongmao Feed Processing Co. All feeds are prepared based on scientific formulas, prepared by aquaculture specialists and researchers from knowledge gained from studies conducted with the various growth stages. The ingredients are imported and include high quality fishmeals, starch with concentrated vitamins, minerals, amino acids, proteins, fats, yeast and trace elements as the additives. The proximate composition of this feed is shown in Table 16 (www.zhongmao.com/english/sljg.htm).

Table 16. Composition of eel feeds produced by Zhongmao Feed Processing Co.

Size	Protein (%)	Fat (%)	Ash (%)	Fibre (%)	Ca (%)	P (%)	Moisture (%)
Adult eels	≥45.0	≥3.0	≤18.0	≤0.8	≥2.5	≥1.5	≥9.0
Glass eels	≥46.0	≥3.0	≤18.0	≤0.8	≥2.5	≥1.5	≥9.0
Medium size	≥48.0	≥3.0	≤18.0	≤0.8	≥2.5	≥1.5	≥8.0
Medium size Grade A	≥48.0	≥3.0	≤18.0	≤0.8	≥2.5	≥1.5	≥8.0

Even though the actual amount of feed consumed by glass eels depends on water and temperature conditions, the recommended initial daily ration is about 30 percent of the total weight of the released glass eels, distributed in several portions. Adequate feeding is important to reduce cannibalism. In about 4 months, glass eels grow to around 7 g and in another 4 months they reach about 100 times their stocking size.

During the early years of eel culture in Japan and Taiwan Province of China, adult eels were fed with silkworm pupae, but in recent years compound feeds have come into common use (Pillay 1995). Figure 31 shows the total amount of artificial feed used in Japan for feeding farmed eels.

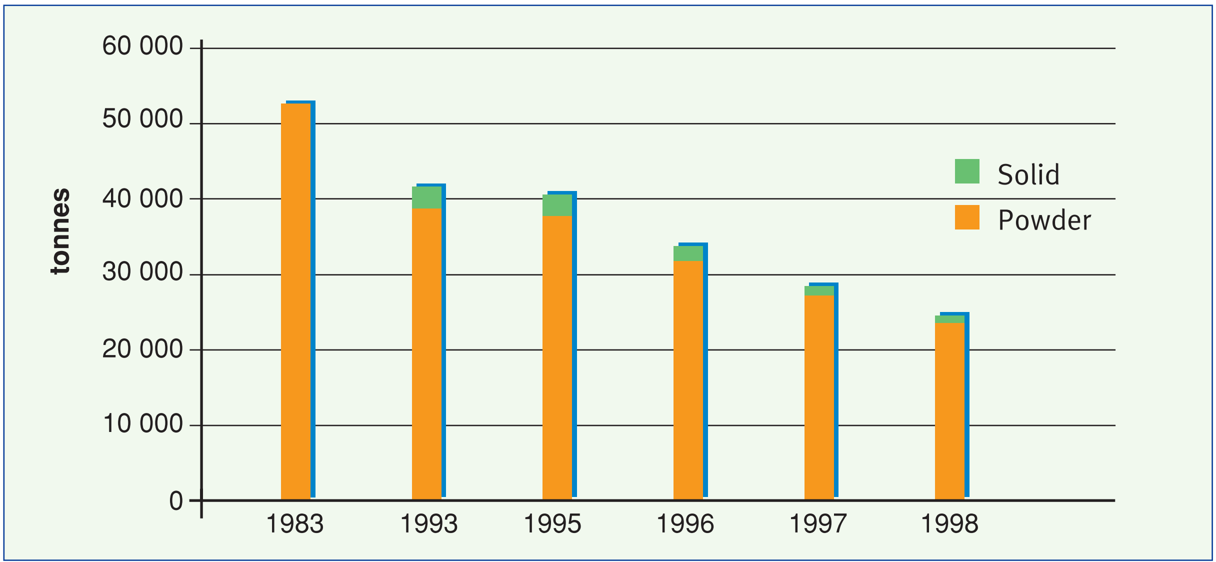


Figure 31. Total eel feed production [solid (pellets) and powder] in Japan (Nakada 2000)

In Italy, eel farmers usually add cheap homogenized fish meat (according to the fishery season) to paste food, while northern European farmers usually employ cod roe (Grandi *et al.* 2000). Generally, adult eels are fed at about 10 percent of the total weight stocked per day, when fresh fish is used. If a formulated diet is employed, it is suggested that it should have 46-52 percent protein and 3-5 percent fat. The roe of Atlantic cod has been recently used in Europe, while in Australia, European carp roe is utilized. De Silva *et al.* (2001) examined four types of roe (European carp, mirror dory, orange roughy and warehou) and showed that European carp and warehou roes were preferred by eels in the latter stages of growth; these two types have significantly higher contents of arachidonic acid.

Changes in feeding affect growth rate and body composition. Garcia-Gallego and Akharbach (1998), monitoring the fatty acid content of body lipids in a fish farm during the production cycle of *Anguilla anguilla* from elvers to commercial size (>100 g), showed that the fat content in the body of eels notably increased in direct relationship with size. Changes in dietary lipid composition (through changing moist natural food to pelleted feeds, or changing from a low to a high fat content) influenced the fatty acid composition of body and muscle lipids. The composition of the three different food types is shown in Table 17. Elvers, initially weighing about 0.2g, doubled their weight in 2 months, even if they showed a certain delay during the transition from initial food (cod roe) to pellet I. Similarly, body-fat content also doubled in this interval. Eventually, the change from pellet I (lower fat) to pellet II (higher fat) resulted in the highest value of body fat accumulation. Some eels kept for 1 year in the farm multiplied their initial weight by a factor of 375 and others by a factor of 10: in any case, the transition from cod roe to pellet I and from this to pellet II encouraged growth rate increases, reflecting a progressively higher energy intake per unit of diet consumed.

It is observed that there is a high degree of fat accumulation in the muscles of cultured eels, compared to the average of wild eels (Sumner *et al.* 1984, Jover *et al.* 1990; Akharbach 1995). Graynoth and Taylor (2000) showed that the maximum growth rates of short-fin eels depends on high quality food, low competition for food and the close to optimum temperatures found in New Zealand. In addition, competition is reduced if eels are grown at high density in turbid water with a high abundance of phytoplankton (Jones *et al.* 1983; Seymour 1989; Degani and Gallagher 1995). Water temperature influences food consumption and the metabolic rate that controls growth (Brett 1979). Low temperatures (8-9°C) cause a cessation of growth, but food supplies, rather than temperature, control growth rate.

Table 17. Composition of feeds for eels (Garcia-Gallego and Akharbach 1998)

	Content (% dry matter)		
	Cod-roe	Pellet I	Pellet II
Protein	76.3	56.4	45.3
Fat	14.0	14.2	29.6

Some studies have shown that the diet should be highly digestible, in order to minimize the release of nitrogen, phosphorus and solids to the aquatic environment. The optimum protein content should be 44.5 percent for Japanese eels (Arai *et al.* 1971, 1972; Nose and Arai 1973), and range from 30 to 48 percent for European eels (Spannhof and Kuhne 1977; Degani, Levanon and Trieger 1984, 1985; Arai, Mas Alvarez and Ogata 1986). Recent studies on the American eel show that optimum growth from 8 to 22 g requires 47 percent protein (Tibbetts, Lall and Anderson 2000). The protein/energy ratio has to be accurately balanced to obtain rapid growth, efficient feed utilization and to give a flesh rich in protein with a low fat content (Tibbetts, Lall and Anderson 2001); this optimization minimizes feeding costs (Tucker 1992). The best results for growth rate, feed efficiency and nutrient digestibility are obtained with a diet with about 22 g DP MJ DE^{-1} (Tibbetts, Lall and Anderson 2001).

The average weight increase of *Anguilla anguilla* fed zero or 10 percent soybean meal in their diet was significantly higher than that achieved when the soybean content was 20 percent (Degani 1987). The body protein (dry weight) of eels fed the highest soybean diet was lower compared to the other experimental groups. However, no significant differences were found in the body fat among the experimental groups. Tanimoto, Koike and Takahashi (1993) showed that feeding eels a commercial diet containing tochu (*Eucommia ulmoides* Oliver: a herb medicine) leaf powder improved cultured eel meat texture. A firmer texture was produced that contained more collagen than the control. American eel elvers are raised on pelleted fish feed to make sure their taste and colour are consistent.

All the feeding trials conducted with cultured eels indicate that the balance between proteins and lipids is critical, not only for growth but also for flesh quality. As seen in other capture-based aquaculture species that are cultured because of their meat quality, the development of better diets assists in the successful marketing of the product.

Fish health and disease

Eels can be cultured at very high densities, making them efficient users of space and culture facilities. However, careful management of the culture system in terms of water quality and temperature is essential if disease problems are to be avoided.

Eels appear to be more susceptible to diseases and resultant mortality than many other aquaculture species. Unstable temperature conditions and the accumulation of uneaten feed are direct or indirect causes of mortality in elvers and adult eels. Temperature changes affect their feeding activity and reduce their resistance to disease. Eels are also very susceptible to low dissolved oxygen concentrations. Table 18 lists the principal pathogens of cultured eels.

Saprolegnia fungal infection, or "cotton cap disease" as it is known in Japan, is a common cause of mortality in Japanese ponds. However, this infection is only a secondary condition; the primary cause of disease is a pathogenic bacterium. This infection occurs in spring and autumn, when temperatures are 15-20°C. The symptoms include white patches on the body of the eels.

Table 18. Specific pathogens of cultured eels

VIRUSES

- ➔ Rhabdoviral dermatitis
- ➔ *Herpesvirus anguillae* (EHVF: "Eel herpesvirus in Formosa")
- ➔ Infectious Pancreatic Necrosis Virus (IPNV)

BACTERIA

- ➔ *Pseudomonas anguilliseptica* (red spot disease)
- ➔ *Edwardsiella anguillimortiferum* (red disease)
- ➔ *Edwardsiella tarda* (liver-kidney disease)
- ➔ *Vibrio furnissii*
- ➔ *Vibrio anguillarum*
- ➔ *red-fin disease*
- ➔ *common enteritis*

PARASITES

Protozoa

- ➔ *Trichodina* sp.
- ➔ *Ichthyophthirius multifiliis* (Ich)

Copepoda

- ➔ *Ergasilus celestis*
- ➔ *Lernaea cyprinacea*

Microspora

- ➔ *Pleistophora* sp. (white spot disease)
- ➔ *Pleistophora anguillarum* (beko disease)
- ➔ *Myxidium* sp. (dermatitis)
- ➔ *Mixobolus* sp. (white spot disease)

Monogenea

- ➔ *Pseudodactylogyrus anguillae*
- ➔ *Pseudodactylogyrus bini*
- ➔ *Gyrodactylus* sp.

Crustacea

- ➔ *Argulus giordani*

Nematoda

- ➔ *Anguillicola crassus*
- ➔ *Anguillicola globiceps*

FUNGI

- ➔ *Saprolegnia* sp. (cotton cap disease)
- ➔ Branchiomycosis

The "red disease" in pond-cultured Japanese eels, caused by *Edwardsiella anguillimortiferum*, is generally reported in the summer when temperatures exceed 28°C but it also occurs in the spring. This pathogen causes macroscopic putrefactive lesions in the kidney or liver, resulting in high mortality rates. The eels that survive develop a strong immunity and are medicated with food containing chloromycetin or sulphadiazine. In Europe, the same disease is said to be produced by *Vibrio anguillarum*, a common pathogen of many marine fish (Pillay 1995).

Edwardsiella tarda is the pathogenic bacteria of the liver-kidney disease of eels, and has caused mortalities in pond culture in China. This disease occurs mainly during the periods from February to May and from October to December each year, and causes serious damage to the eel culturing industry in Chaozhou, Guangdong Province (Quanzhang and Xinling 1994). In Japan, *Edwardsiella tarda* causes mortalities during all stages of eel culture, and particularly at the glass eel (*Anguilla japonica*) (post-larval) and elver (young eel) stages (Salati, Ono and Kusuda 1991). *Pseudomonas anguilliseptica* is the aetiological agent of "red spot disease" or "*Sekiten-byo*" in the Japanese eel. This bacterium, although less common in European eels, has been found in The Netherlands by Haenen and Davidse (2001) causing low levels of mortality at high temperatures (15-25°C in *A. anguilla*). The symptoms include a pale body, petechial haemorrhage in the back and tail, liver haemorrhage and congested posterior kidney.

A toxigenic vibrio (*Vibrio furnissii*), detected in *A. anguilla*, is also pathogenic for eels, causing necrotic areas, fluid accumulation in the body cavity and a swollen intestinal tract in elvers (Amaro, Biosca and Garay 1995). Japanese eels are also affected by rhabdoviral dermatitis, caused by a virus that makes fish moribund, with cutaneous lesions, necrosis of the dermal strata, haemorrhage and inflammatory cellular infiltration; it occurs at temperatures between 15°C and 20°C but not at 25°C; for this reason this kind of disease never appears in warm water environments (Kobayashi, Shiino and Miyazaki 1999).

Trichodina sp., is a parasite found in European eels cultured in re-circulation systems in Denmark. Production there is based on imported glass eels (from France) or elvers caught in river estuaries along the European Atlantic coast (Madsen, Buchmann and Mellergaard 2000); this is thought to be the likely source of the infection. The "white spot disease" is caused by parasitic sporozoa-like species (*Pleistophora, Myxidium and Mixobolus*) and affects mostly elvers but sometimes also adults. This disease affects the kidneys and muscles: the bodies become black, with disappearing patches of pigmentation and the animals swim vertically (Pillay 1995). *Anguillicola crassus* is a parasite affecting Japanese and European eels; these species seem to have not developed any antibody response in laboratory experiments (Haenen *et al.* 1996). Between 30 and 100 percent of European eel populations are infected by this nematode. In Europe, it was first recorded in 1982 from eels from the Weser-Ems region in northern Germany, but soon it occurred in many other German localities (river basins of the Elbe, Weser and Rhine, water bodies of Berlin) as well as in Holland, Belgium, Denmark, northern Italy and England (Moravec 1992). In 1998 it was found in the river Erne in Ireland (Evans, Matthews and McClintock 2001).

The parasite *Anguillicola crassus*, together with the swim-bladder nematode (*A. globiceps*), affects farmed and wild populations of both *Anguilla japonica* and *A. anguilla*. *Anguillicola crassus* is found in Japan, the Republic of Korea, Taiwan Province of China, and China, while *A. globiceps* is reported only in Japan and China. These nematodes use cyclopoid copepods as intermediate hosts. Other known intermediate hosts of *A. crassus* are *Eucyclops serrulatus* (Japan) and *Thermocyclops hyalinus* (Republic of Korea), and *Mesocyclops leuckarti*, *T. hyalinus*, *T. taihokuensis*, *E. serrulatus*, *Acanthocyclops viridis* and *Cyclops strenuus* (China). *A. globiceps* and *A. crassus* show a seasonal occurrence in *T. hyalinus* with a high prevalence in summer. Paratenic hosts are as yet unknown in Asia. *A. crassus* is relatively common in farmed and wild populations of Japanese eels in Asia, but *A. globiceps* is usually found only in wild populations of Japanese eels in Japan and China. In culture ponds, *A. crassus* is more prevalent and abundant in European eels than in Japanese eels. Although *A. globiceps* merely induces the thickening of the host's swim bladder wall, *A. crassus* has severe pathological effects on European eels and heavy infection leads to host mortality. The prevalence of *A. crassus* in Japanese eels cultured in Japan and the Republic of Korea is relatively low in winter, whereas the prevalence of *A. globiceps* in wild populations of Japanese eels from Japan is high in winter (Nagasawa, Kim and Hirose 1994).

Other infections are caused by the crustacean parasite *Argulus giordani*, found frequently in "*valli*" culture (Italy); the anchor worm *Lernaea cyprinacea* in Japanese ponds (which can now be simply prevented by repeated troclorform baths, or "cured", for example by removal by hand); and *Ichthyophthirius multifiliis*, which causes "ich" (Pillay 1995).

A branchial kidney disease (Branchionephritis) has been identified in Japan, but the causes remain uncertain. It has caused considerable economic losses in eel farms. This disease makes the skin of the gill lamella swell, causing adhesion, and the inflamed kidneys show signs of bleeding (Pillay, 1995) In 1988, a new virus was isolated from both the Japanese eel (*Anguilla japonica*) and the European eel (*A. anguilla*) cultivated in an intensive culture system in Japan. This virus was designated *Herpesvirus anguillae* (eel herpes virus).

The microsporean *Pleistophora anguillarum* is the etiologic agent of "*beko* disease", which affects *Anguilla japonica* in Taiwan Province of China. This parasite attacks the muscle tissues, prominently the skeletal muscle (Kou and Lo 1994). Other eel diseases reported in Taiwan Province of China are parasitic diseases, enteritis type bacterial diseases (red-fin disease, red-spot disease, vibriosis, edwardsiellosis and common enteritis), fungal diseases (branchiomycosis and saprolegniasis), gill diseases (gas disease and gill ulcer) and diseases caused by water quality, deformity, nutritional disease, and drug injuries which evolve into diseases (Shih, Lu and Chen 1993). IPNV (Infectious Pancreatic Necrosis Virus) (Hsu, Chen and Wu 1993) and EHVF (Eel Herpesvirus in Formosa) are found in Taiwan Province of China (Shih, Lu and Chen 1993) in cultured Japanese eels.

A study carried out in three Canadian grow-out facilities (Nova Scotia, Newfoundland, and New Brunswick) identified two common gill parasites *Pseudodactylogyrus anguillae* (Monogenea) and *Ergasilus celestis* (copepoda) on wild *Anguilla rostrata* (Barker and Cone 2000). *Pseudodactylogyrus* species (*P. anguillae* and *P. bini*) are also found in *A. anguilla* (Buchmann 1993).

Brief accounts are provided of other infectious and parasitic diseases of eels, particularly in Australian eels. Included are: aeromoniasis, or red fin disease; *Myxidium dermatitis*; *Myxobolus* infection; *Trichodina* infection; white spot disease, or Ich; *Pseudodactylogyrus* and *Gyrodactylus* gill parasites; *Anguillicola* roundworm; saprolegniasis; and a leech, *Zeylancobdella* (Gosper 1995). Excessive levels of oxygen and nitrogen in water can cause bubble-like tumours in elvers; in some cases gas can be found in muscles and blood vessels. The symptoms can be cured by introducing clean water at lower temperatures (Pillay 1995).

Although eels are extremely susceptible to many fish diseases, most can be minimized by careful control of imported glass eels and elvers, and by good management and husbandry systems that manage water quality, temperature and oxygen levels. Any stress can lead to the development of a disease.

Harvesting systems

Eel culture generally involves partial harvesting, grading and stocking at regular time intervals. Due to the intense nature of many culture systems, harvesting techniques are usually relatively simple, though care is needed to minimize the stress induced by harvesting. Normally, feeding is suspended the day before harvesting. When the eels reach a marketable size, harvesting is carried out with a scoop net in the feeding area, when the eels congregate at the usual feeding time. During harvesting, oxygen levels are kept high by admitting freshwater into the culture system or by direct oxygenation (Pillay 1995).

During the summer in Japan, when water conditions are poor and the eels do not group together, a seine net is used to herd the eels towards the inlet area of the pond, where they are harvested using small dip nets. This seining procedure is successively repeated to oxygenate the pond. In winter, eels are harvested by draining the ponds on warmer days. Generally, harvesting takes place in the morning because the eels follow the water flow and do not burrow into the bottom. If they do, a T-shaped wooden scraper can be used to harvest them. If a large number of eels should remain in the pond, the pond can be refilled and drained during the night, causing the eels disturbed by drainage to exit (Pillay 1995). After harvesting, eels may be placed in cages and sprayed with well water at a low temperature (about 15°C) for a short time before shipping for consumption (Kobayashi *et al.* 1999).

In Australia, eels are harvested from 150 g to a few kilograms in size, depending on the target market. Harvesting may be carried out by draining the pond using a net attached to the outlet pipe, using a seine net, or using a scoop net at feeding time. The eels are sorted into different sizes using a grading tray. They are then placed into holding tanks for several days without feed to purge their stomachs. Chilling and packing into strong plastic bags with just enough water to ensure that their skin remains moist follows. Eels can breathe through their skin, so the bags are filled with oxygen for transportation to market (www.dpi.qld.gov.au/fishweb).

Marketing

There are numerous markets for eel products, including human consumption, fish bait, aquarium and fish feed markets. Internationally, market prices for cultured eels and eel products vary with species, country, product type and quality. The principal markets for eels are in Japan and Europe. However, the eel trade is unusual in many respects, because eels and eel products are consumed at all stages of their life cycle – e.g. as jellied eels (a glass eel product) and as smoked eel (a yellow or silver eel product). Eels of all sizes are supplied to Oriental markets and are considered a delicacy. Suppliers to this market are willing to pay “top dollar” for adult eels and exorbitant prices for glass eels destined for consumption and/or grow-out.

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 future could limit the profitability of the eel farming industry. For example, American glass eel prices in the USA rose over 500 percent between 1994 and 1998. In the past 20 years prices for live glass eels have been as high as US$ 2 200/kg, 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 2001).

The price of glass eels reached US$ 9 000/lb (US$ 19 845/kg) in China in 1996 (Anonymous 1996). Data on quantities and market prices vary widely from country to country, and even within the same country.

The number of glass eels per kilogram varies according to the species:

- *Anguilla anguilla* – the count is between 2 800 and 4 000 pieces/kg. Generally the glass eels are larger at the start of the season. The average annual count would be 3 200 pieces/kg.
- *Anguilla japonica* and *Anguilla rostrata* – the number of pieces per kilogram is considerably higher than *Anguilla anguilla*, namely between 5 000 and 6 000 pieces per kilo (www.glasseel.com).

One regional market for eels is Europe. Direct consumption of glass eels (e.g. in Spain, Italy and Portugal) is reported to be relatively low and, presumably, prices are lower for these glass eels than for those destined for stocking purposes. In Denmark this market is not a price leader, and the development here is not a threat to the same extent as the overseas market (Frost *et al.* 2000).

Glass eels are eaten raw or are fried in oil much like onion rings. Adult eels are smoked (continental Europe), jellied and stewed (London method), and, primarily, processed as "*kabayaki*". Over 70 percent of global production is for the Japanese "*kabayaki*" market. "*Kabayaki*" is a style of serving, where eels of around 150-200 g are butterflied, placed on skewers, basted (marinated) in a thick soy based sauce, and steamed or grilled. More than 90 percent of eels consumed in Japan are served this way, with eels being the most widely consumed freshwater fish in Japan. As of July 2001, the market price for live eels averaged US$ 12.50/kg (Tibbetts 2001). In restaurants in Japan, where eels are considered a healthy food, an eel dish can cost between US$ 20 and US$ 32/kg. The latter price represent the value of "*futo*", what the Japanese call eels weighing 250-500 g (www.bangkokpost.net/education/site2000/ptdc1500.htm).

After harvesting, eels are rapidly sorted into different sizes. Japanese eels reach 100-200 g after one year, and Japanese consumers prefer sizes of 120-150 g or 160-250 g, depending on the region. European markets prefer larger sizes of around 250 g, so Japanese eels of this size, not consumed in Japan, are generally exported to Europe.

Although global eel aquaculture production expanded from 1990 to 2000, the economic value has decreased. It peaked in 1994-1995 at US$ 1.4 billion and decreased to US$ 975 million in 2000 (Figure 32). However, FAO data does not include the value of around 50 000 tonnes of European eels that are produced annually in China.

Asia was at the top producer in 2000 with a production of US$ 889 million, followed by Europe with a production valued US$ 85 million. The production of eels by aquaculture by developing countries was valued US$ 569 million in 2000 and accounted for 58 percent of the global production value. China was the leading country with a value of US$ 289 million. In the same year, the farmed output of industrial countries was valued at US$ 405 million (Japan = US$ 320 million). Together, China and Japan accounted for 63 percent of the total value.

The value of European eels cultured in Europe remained fairly steady from 1991 to 2000 at about US$ 80 million (Figure 33). The European eels produced in China are not included in FAO data.

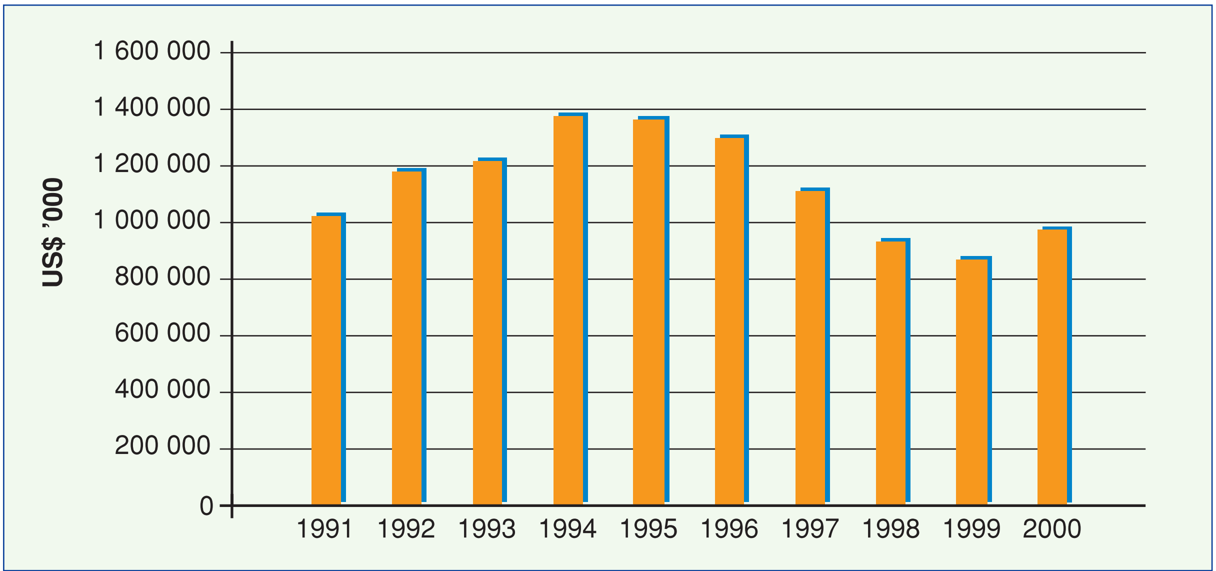


Figure 32. Global value of eel aquaculture (1991-2000) (FAO 2002a)

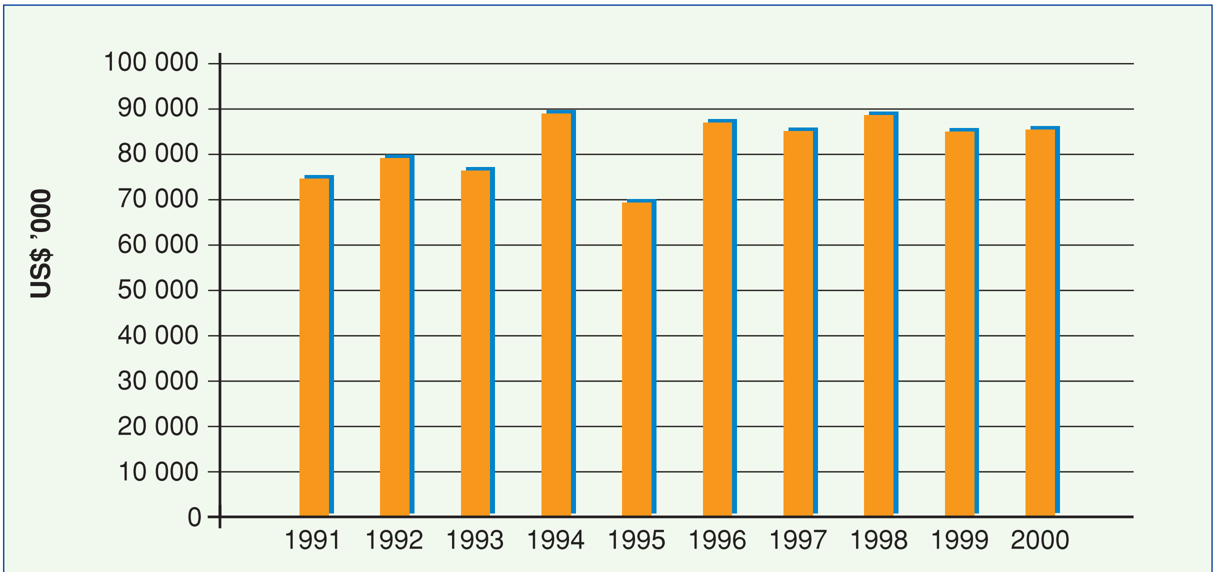


Figure 33. Value of European eels (*Anguilla anguilla*) cultured in Europe (1991-2000) (FAO 2002a)

The leading European producer in 2000 was the Netherlands, followed by Denmark and Italy (Table 19).

The trend in the value of the other important commercial species – Japanese eels (*A. japonica*), produced only in Asia, increased between 1991 and 1994/95 but then declined to a lower level in 2000 than in 1991 (Figure 34). In 2000, the leading producer was Japan, followed by China (Table 20).

The annual production of Japanese eels in Taiwan Province of China generally declined during the decade 1991-2000, with a peak of nearly 56 000 tonnes in 1991 and a trough of under 17 000 in 1999, rising again to about 30,000 tonnes in 2000, and the value fell from US$ 414 million in 1991 to US$ 229 million in 2000 (Fishstat Plus 2002). In addition to exporting eels for foreign exchange earnings, eels are also a popular seafood in the domestic market of Taiwan Province of China. This domestic market is growing rapidly and eel aquaculture is an undoubtedly a highly

Table 19. Production of European eels (*Anguilla anguilla*) by country in 2000 (FAO Fishstat Plus 2002)

Country	Value (US$ '000)
Netherlands	31 006
Denmark	24 066
Italy	18 079
Spain	3 699
Greece	3 090
Sweden	1 593
Germany	1 494
Belgium	825
France	525
Macedonia	450

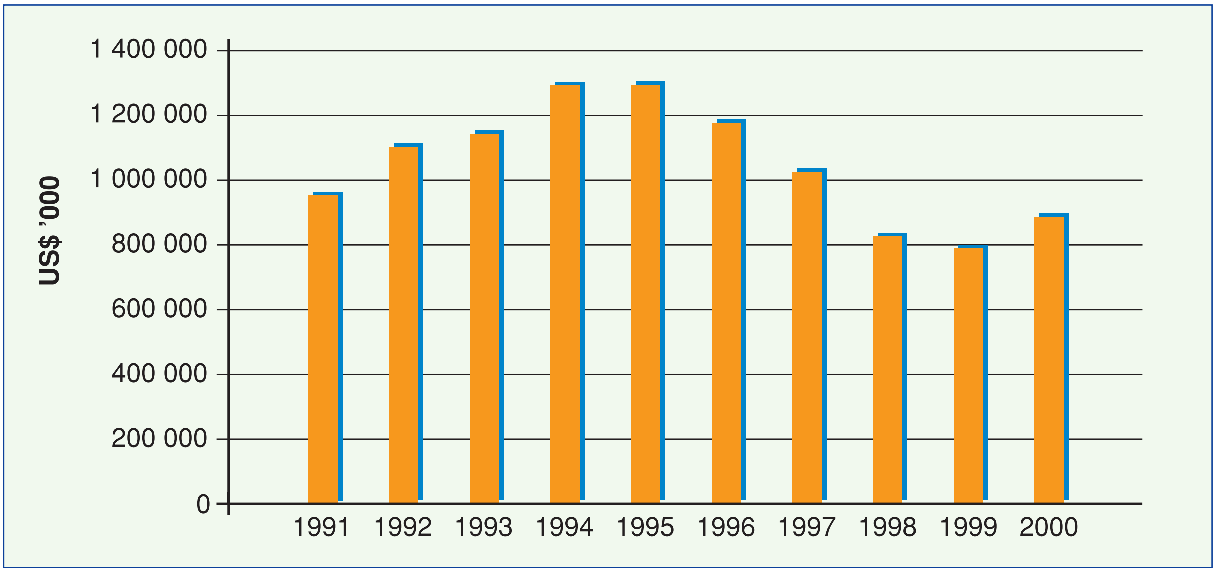


Figure 34. Trends in the value of Japanese eel (*Anguilla japonica*) aquaculture (1991-2000) (FAO 2002a)

Table 20. Japanese eel (*Anguilla japonica*) aquaculture production value by country in 2000 (FAO Fishstat Plus 2002)

Country	Value (US$ '000) in 2000
Japan	320 769
China	289 332
Taiwan Province of China	229 483
Republic of Korea	30 647
Malaysia	14 861

lucrative and profitable industry. The main export market for Taiwan Province of China is Japan, which takes up to 90 percent of its eel exports (www.american.edu/projects/mandala/TED/eelfarm.htm).

In other Asian countries, eels are regarded as an "actively energetic" animal, and they have been associated for centuries with imparting strength and energy to humans (Wu 1999). This traditional thinking by Japanese and people from Taiwan Province of China, especially men, has led to their consuming eels in order to energize themselves and to pursue power. In particular, they believe that eels may help to improve or increase their sexual prowess.

The annual consumption of eels in Thailand is about 300 tonnes (www.bangkokpost.net/education/site2000/ptdc1500.htm), of which 20 tonnes comes from an eel farm in Chacheongsao, with the rest being imported as "*kabayaki*" from Taiwan Province of China and Japan. Eels can fetch as much as US$ 32/kg, twice the price of good-quality shrimp (www.bangkokpost.net/education/site2000/ptdc1500.htm).

Most of the Australian production is exported to European (Germany, Netherlands) and Asian markets (Hong Kong, Taiwan Province of China and Japan) as adults (>1 kg) as fresh, chilled or frozen whole fish. The "*kabayaki*" markets prefer eels weighing 200 g and Australian short-fin eels can be grown to this size in 12 to 18 months. *A. australis* closely resembles the Japanese eel *A. japonica*, in both appearance and taste.

The Japanese prefer eels that are uniform in colour, so the potential for *A. australis* in this market is high. As such, the short-fin eel is well accepted there and attracts similar prices to *A. japonica*, averaging around US$ 10-15/kg at the farm gate (live) when sold to Japan. The farm gate prices for short-fin eels that are destined to be sold to China are much lower (US$ 3-4/kg). There is potential for Australian producers to export all of their short-fin eel production to Japanese markets. Despite the high price paid for "*kabayaki*" eels, marketing of large eels (up to 5 kg each) into alternative markets may be equally if better in terms of financial returns (www.fisheries.nsw.gov.au/aquaculture/freshwater/eels.htm).

While there have been fluctuations in eel markets for years, it was not until the mid-1990s that eel prices began skyrocketing due to enhanced demand and dwindling supplies. One report shows that the estimated value of glass eels rose over 500 percent between 1994 and 1998 (www.ecoscope.com/eelnews.htm).

Eels are traded globally (import/export) in canned, frozen, smoked, fresh or chilled forms; live elvers and eels are also traded. FAO data does not report processed eels such as "*kabayaki*", which account for most of eel trade in the Japan (at least 60 000-80 000 tonnes imported every year) and Japanese consumption. FAO data shows that global import volumes increased from more than 74 100 tonnes in 1990 to over 103 000 tonnes in 1999 (Figure 35); around 62 000 tonnes of this comprized canned river eels.

In 1999, 103 617 tonnes of eels were imported globally, mainly by Asia (84 904 tonnes), Europe (17 167 tonnes) and North America (1 532 tonnes). The lead importing country was Japan (Figure 36), with more than 68 300 tonnes (56 717 tonnes canned river eels and over 11 600 tonnes of live eels and elvers), followed by Taiwan Province of China, whose imports were mostly frozen eels.

The most imported eel commodity in 1999 was canned river eels, with a total of 62 279 tonnes (Japan 56 717 tonnes, Austria 5 094 tonnes, Taiwan Province of China 447 tonnes, etc.), followed by live elvers and eels (26 528 tonnes). Frozen eel imports were 12 856 tonnes (Taiwan Province of China 9 402 tonnes, USA 702 tonnes, Germany 691 tonnes, etc.). Fresh or chilled eel imports were 1 675 tonnes (Spain 565 tonnes, Germany 440 tonnes, Denmark 158 tonnes, Belgium 100 tonnes,

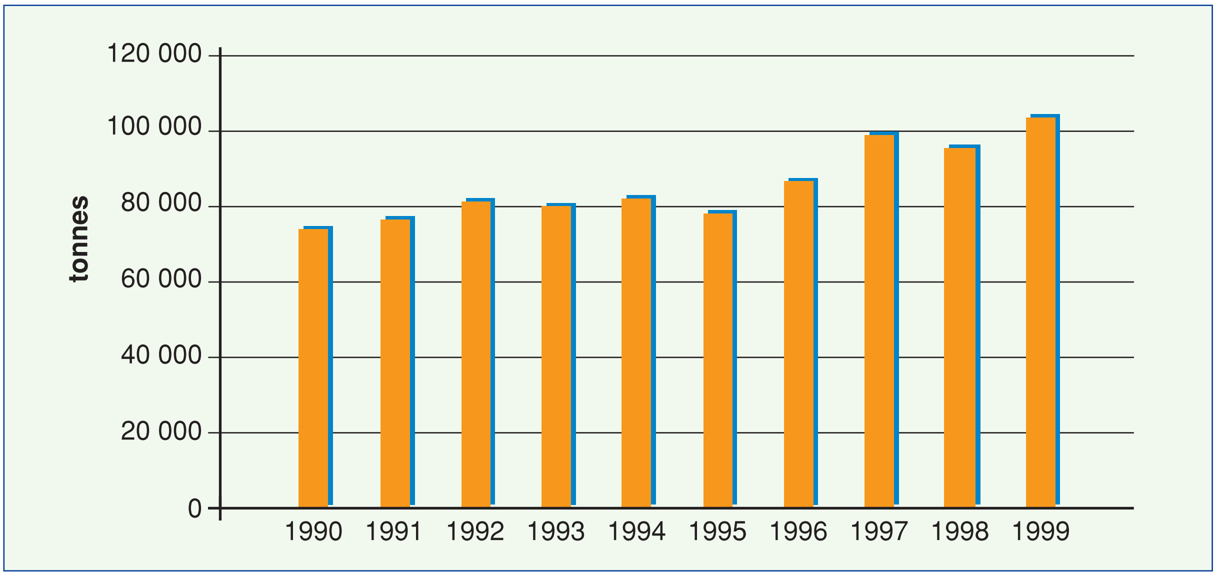


Figure 35. Value of global eel imports (1990-1999) (Fishstat Plus 2002)

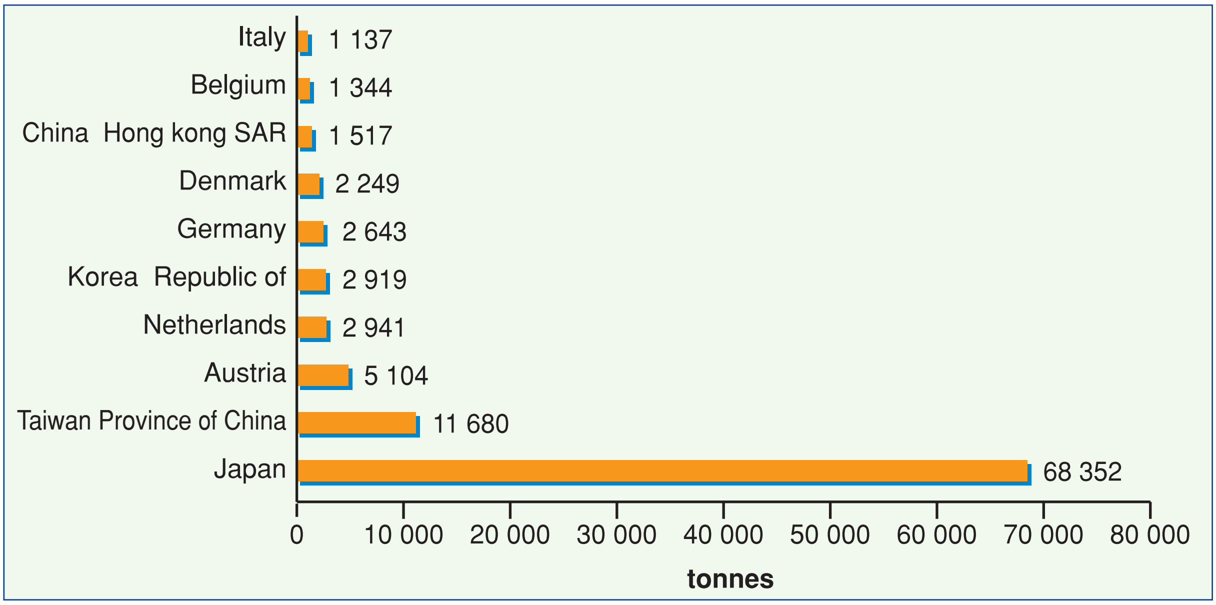


Figure 36. Imports of fresh eels by country in 1999 (Fishstat Plus 2002)

etc.) and smoked eels 279 tonnes (Denmark 102 tonnes, Belgium 62 tonnes, Germany 60 tonnes, etc.).

In 1999, total import value of eel products was over US$ 1 billion, the leading country being Japan (Figure 37), followed at a far lower scale by China and the Republic of Korea.

Eel commodities are also exported; the trends 1990 to 1999 are shown in Figure 38. In 1999, 39 016 tonnes were exported (valued at US$ 362 million), with Asia being the leading continent (21 790 tonnes), followed by Europe with 14 496 tonnes, and Oceania with 1 264 tonnes.

In 1999, the leading exporting country was China with 9 149 tonnes, followed by Taiwan Province of China. Third was the leading European exporter of eels, Denmark (Table 21). However, other sources show that China exports far more eels than the FAO data indicate, some 120 000 tonnes in 2001. The top ten exporters of eels by value are shown in Table 22.

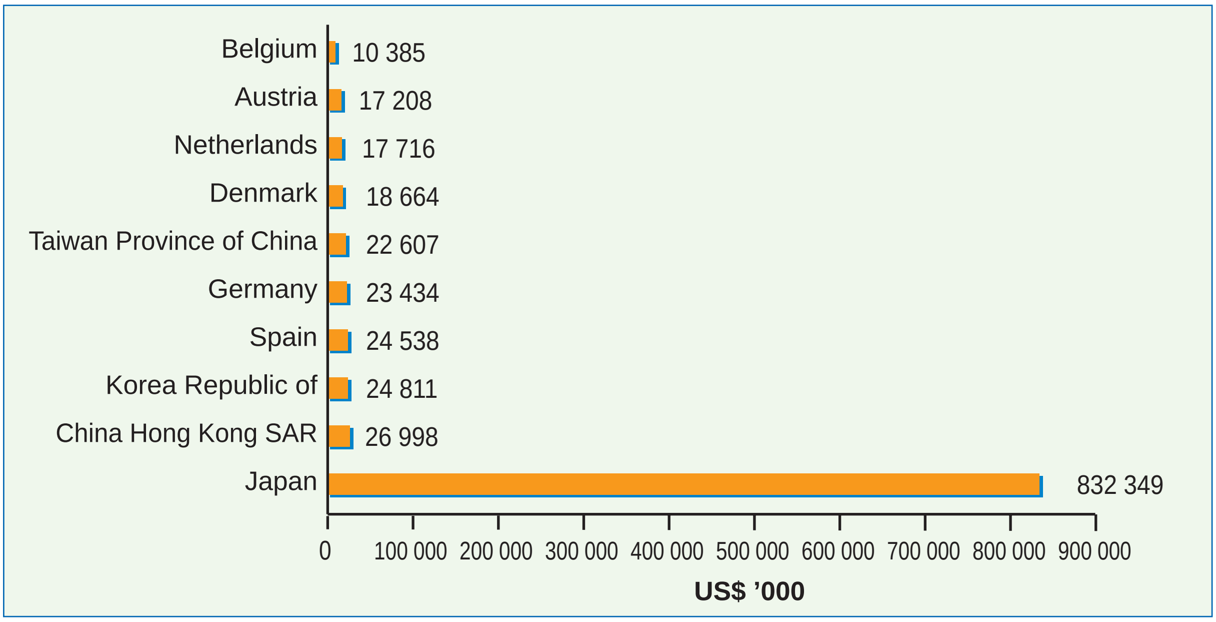


Figure 37. Top ten eel importing countries by value in 1999 (Fishstat Plus 2002)

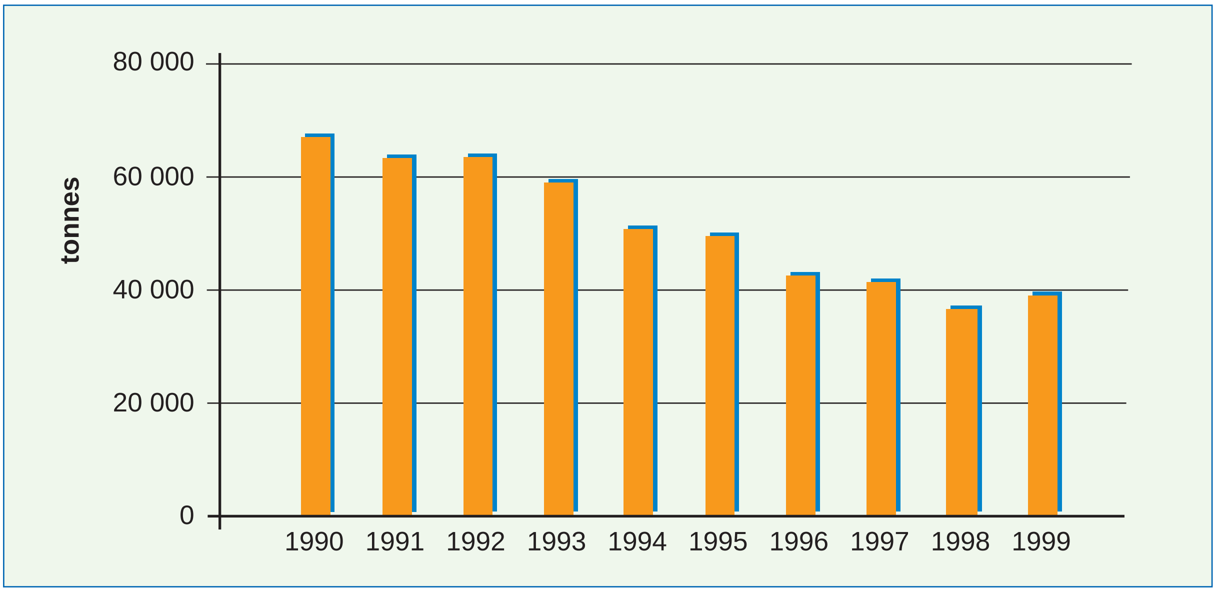


Figure 38. Quantity of eel exports (1990-1999) (Fishstat Plus 2002)

From 1990 to 1999, the production of eel commodities, mainly consisting of canned river eels, peaked in 1994 and then declined until 1999 (Figure 39). The total in 1999 was 27 640 tonnes, mainly canned river eels; China being the leader (25 000 tonnes). China was also the lead country for frozen eel production (548 tonnes), with Denmark (354 tonnes) second and Canada (331 tonnes) third. Processed eels such as "*kabayaki*" are not included in FAO data, even though this is the main commodity for which eel capture-based aquaculture production is destined.

The information in Tables 23-28 has been extracted from Japanese monthly trade data (www.wtco.osakawtc.or.jp/e/market/item/eels.html). Japan, as a leading market for eel products, can be considered as an example of the commodity trade in eels and eel products (data source: Statistics from Japan Trade Monthly). The totals for imports of fresh and processed eels over the past few years are shown in Table 23, while the type of products imported in 1998 are given in Table 24.

Table 21. Top ten exporters of eels by volume in 1999 (Fishstat Plus 2002)

Country	Quantity (tonnes)
China	9 149
Taiwan Province of China	8 763
Denmark	5 780
Netherlands	2 079
Sweden	1 900
India	1 843
United Kingdom	1 047
Italy	1 043
New Zealand	840
Canada	796

Table 22. Top ten exporters of eels by value in 1999 (Fishstat Plus 2002)

Country	Value (US$ '000)
Taiwan Province of China	117 712
China	57 297
Denmark	42 110
France	36 692
Netherlands	18 721
United Kingdom	15 079
Spain	13 745
Japan	10 200
Italy	8 741
Sweden	6 474

As Table 24 shows, processed eels made up 75 percent of imports in 1998. The main sources, types and values of Japanese eel imports are shown in Tables 25 and 26.

The Japan Times reported that Japan imported 133 200 tonnes of eels in 2000, 99.9 percent of which came from China and Taiwan Province of China (www.japantimes.co.jp/cgi-bin/getarticle.pl5?nb20010706a1.htm). The Japanese consume more than 110 000 tonnes of eels per year, while domestic production is only about 30 000 tonnes (www.dpi.qld.gov.au/fishweb/2691.html). Of the eels consumed, 60 percent come from China, and another 20 percent from Taiwan Province of China. Chinese producers charge about 600 Yen/kg compared to domestic farms that sell eels for 1 000 Yen/kg or more.

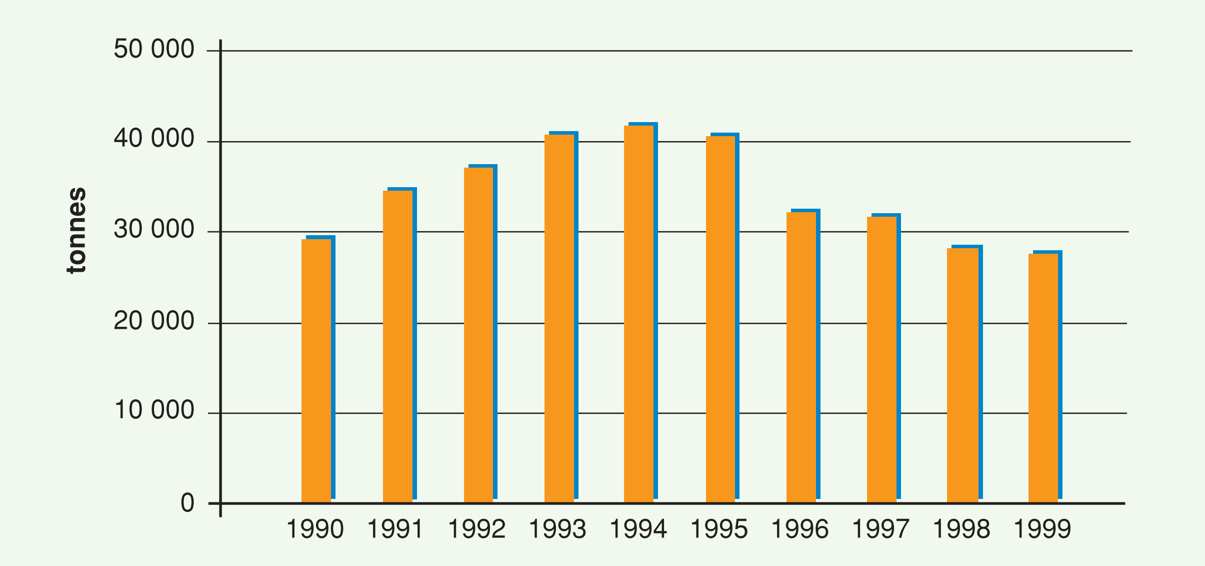


Figure 39. Trends in eel commodity production (1990-1999) (Fishstat Plus 2002)

Table 23. Trends in Japanese eel imports (1994-1998)

Year	Volume (tonnes)	Value (million Yen)
1994	54 844	114 198
1995	48 128	108 797
1996	56 945	123 554
1997	68 910	137 182
1998	65 049	112 347

Table 24. Nature of Japanese eel commodity imports in 1998

Commodity	Quantity (tonnes)	Value (million Yen)
Fresh eels	13 047	27 626 (24.6%)
Processed eels	52 002	84 721 (75.4%)

Table 25. Source and value of fresh eel imports by Japan (1998)

Country	Value (million Yen)
Taiwan Province of China	14 069 (50.9%)
China	7 978 (28.9%)
Hong Kong	4 542 (16.4%)
Malaysia	861 (3.2%)
Others	176 (0.6%)

Table 26. Source and value of processed eel imports by Japan (1998)

Country	Value (million Yen)
China	76 746 (90.6%)
Taiwan Province of China	5 566 (6.6%)
Malaysia	1 645 (1.9%)
Others	764 (0.9%)

Japan also exports eels, but only in limited quantities. Fresh eel exports in 1997 and 1998 are shown in Table 27 and the main destinations in Table 28. These exports appear to be of wild Japanese eels, imported directly by Japanese restaurants in Taiwan Province of China and Hong Kong.

Table 27. Eel exports by Japan

Year	Value (million Yen)
1997	138
1998	119

Table 28. Destination of eel exports by Japan

Country	1997 (million Yen)	1998 (million Yen)
Taiwan Province of China	138	98
Hong Kong	-	21

In Japan, eel businesses and other users are increasingly looking for greater simplicity (e.g. being able to cook unseasoned and seasoned grilled eels in individual packs suitable for microwave ovens or boiling water) and cheaper, more dependable supplies. Demand is also shifting from fresh to processed eels as a result of advances in processing, and imports of processed eel from countries such as China (www.wtco.osakawtc.or.jp/e/market/item/eels.html). Although imports from China and Taiwan Province of China are mainly of Japanese eels (the same species that is captured and cultured in Japan), the use of cheaper European eels for processed is increasing. The profitability of farming European eels could be increased by accessing these markets. Imports of glass eels for farming are not subject to import duty, but duties on fresh eels and processed eels are currently 5 percent and 9.6 percent respectively, when used for direct consumption.

Very few eels are sold live to consumers in Japan; 91 percent of final sales are in the form of processed products. From the farm to the processor, live eels pass through a complex distribution network. Three main problems threaten the Japanese eel industry in the next decade: strong competition from Taiwan Province of China and Chinese products; a new gill disease of unknown aetiology prevalent in intensive indoor culture, and growing public concern about the impact of farm effluents on the environment (Gousset 1992).

The European eel market is very diversified in terms of the quality of the requested products (ranges in size and types of preparation, etc.), the mean selling prices, and the preferred periods of consumption in each country.

There are two main markets in Europe: one for eels with an average weight of 150 g and the second for those above 300 g, most of which are entering the market as smoked eels. Smokers and traders are increasingly asking for well-graded soft eels, which is a quality mark that goes hand in hand with young fast growing eels. The demand for eels in Germany, the Netherlands, France, Denmark, Sweden and England is approximately 13 000 tonnes annually, for eels weighing 125-1 000 g (Tibbetts 2001). The main consuming countries are Italy, Germany and the Netherlands, which account for 80 percent, while 90 percent of the production comes from Italy, France, Denmark and the Netherlands (Petit and Rigaud 1993). Responding to a large demand in Europe at that time, Petit and Rigaud (1993) reported that there had been an increase in the import of other eel species, live or frozen (many cases without any sanitary control) at prices far below those of the native species. In 1999, the production of farmed eels clearly exceeded demand in Europe, a development that started in 1998. New farms had come on stream, while the market had not expanded and so could no longer consume the eels being produced. At the same time the Japanese market appeared almost inaccessible because of cheaper "*kabayaki*" (marinated roast eels) coming from China (Frost *et al.* 2000). This was unfortunate, since European expansion was to a large extent based on the establishment of Danish "*kabayaki*" plants. This had a detrimental effect on the prices for adult eels, and many farms saw their standing stock rise because of unsold eels (www.danafeed.dk/upl/doc/3.doc).

High Japanese market demand for "*kabayaki*" increases the price for European glass eels but the higher supply of "*kabayaki*" eels means price reductions for adult eels in this market. However, the European consumer market for eels is not thought to be linked with the Japanese market by Frost *et al.* (2000). There is still a demand from Spain for glass eels (20 tonnes in 1997) for direct consumption at Christmastime. This market is very flexible and nearly invisible. In 2002 a considerable amount of production was diverted to the Spanish market prior to Christmas, which in turn created a shortage for Asia, and a subsequent sharp rise in prices.

The unrelated and often local marketing activities of European producers and Asian markets are creating a volatile and uneconomic situation for producers. The industry relies heavily on glass eels and elvers for final production. When these are directly consumed, then the industry faces a shortfall of "seed" and, later, larger eels. This will drive the price up in Asian markets, creating another imbalance, while Europe continues to trade at lower prices. Eventually this could see a rise in European prices, or a fall in sales, further weakening the stability of the global eel market. Greater communication and planning is needed to stabilize the market.

Conclusions

Globally, capture-based eel culture is still dependent on the capture of wild "seed", but most eel stocks are overexploited. The main problem is the trade in glass eels and elvers, often caught for direct consumption and fetching higher market prices. The terminology for these life stages of eels is vague (glass eels or elvers), making it difficult to estimate the real trade in "seed material". The marketing of "seed" and adult eels is complex and data sources conflict with each other, even within the same country.

Apart from some differences in the reporting and statistics available, the capture-based aquaculture of eels suffers from many of the difficulties seen in the other selected species dealt with in this report. On the negative side, the sourcing of “seed material” and the lack of other sources is a major concern for the future of the sector. However, the fact that eel feeds are available and that culture techniques (especially re-circulation systems) have very low environmental impacts and require limited land are positive factors.

chapter 4

GROUPERS

4

GROUPERS

Introduction and species identification

Groupers (class Actinopterygii, order Perciformes, family Serranidae, subfamily *Epinephelinae*) are classified in 14 genera of the subfamily Epinephelinae, that comprises at least half the 449 species in the family Serranidae (Tucker 1999). There are 15 major grouper species that are cultured; the dominant species varies 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*. Also cultured in smaller amounts are *E. amblycephalus*, *E. fuscoguttatus*, *E. lanceolatus, E. sexfasciatus, E. trimaculatus, E. quoyanus, E. bruneus, Cromileptes altivelis, Plectropomus leopardus* and *P. maculatus*. In the literature, *E. tauvina* is often referred to but it is very probably a misidentification of *E. coioides* (or *E. malabaricus*), as it has not been confirmed from most economies in the region, with the exception of Taiwan Province of China (Heemstra and Randall 1993). Moreover, reports of *E. akaara* caught in central and southern Viet Nam may be misidentifications of *E. fasciatomaculosus* (Sadovy 2000). In the south eastern USA and the Caribbean, *E. striatus*, *E. itajara*, *Mycteroperca microlepis* and *M. bonaci* seem to have good farming potential (Tucker 1999).

Juveniles and adults of some grouper species live in coastal 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 at least their first few weeks drifting with the oceanic plankton. As they become juveniles, groupers settle in shallow waters where they can find hiding places. At first, wild grouper larvae eat copepods and other small zooplankton, then larger crustaceans - amphipods and mysid shrimp. Wild juveniles and adults eat fish, crabs, shrimp, mantis shrimp, lobsters and molluscs (Tucker 1999).

The maximum size ranges from 12 cm for Pacific groupers (e.g. *Paranthias colonus*) to more than 4 m (e.g. *Epinephelus lanceolatus*); most groupers that have been studied mature within 2-6 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, species like the Nassau grouper (*E. striatus*) spawn in large aggregations (hundreds to thousands of fish) with a sex ratio nearing 1:1 (Sadovy and Eklund 1999).

Groupers are some of the top predators on coral reefs, and tend to be piscivorous K-strategists demonstrating slow growth, late reproduction, large size and long life-spans which make them vulnerable to over-exploitation. They are sedentary in character and strongly territorial (Bullock *et al.* 1992; Heemstra and Randall 1993; Sadovy 1996; Domeier and Colin 1997; Sadovy and Eklund 1999; Morris, Roberts and Hawkins 2000). Tables 29-36 summarize the characteristics of these species, while Figures 40-55 illustrate their appearance and geographical location.

Epinephelus coioides (Hamilton, 1822)

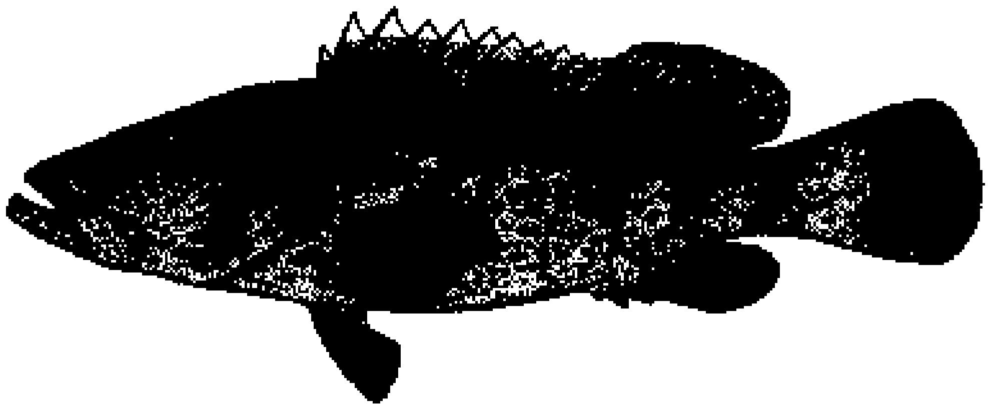


Figure 40. Orange-spotted grouper (*Epinephelus coioides*) (FAO)

Table 29. Characteristics of the Orange-spotted grouper (*Epinephelus coioides*) (FishBase 2002, modified)

Common name	Orange-spotted grouper.
Size and age	Maximum length of 100 cm SL (male/unsexed); maximum weight of 15 kg; can live for 22 years.
Environment	Lives in brackish and marine waters; lives to a depth of 100 m.
Climate and latitude	Subtropical (38°N-33°S).
Resilience	Population doubling time of 1.4-4.4 years, with medium resilience.
Distribution	Indo-West Pacific, south to at least Durban, south Africa and eastward to Palau and Fiji, north to the Ryukyu Islands, south to the Arafura Sea (Russell and Houston 1989) and Australia.
Biology and ecology	Present in turbid coastal reefs (Lieske and Myers 1994) and in brackish water (Randall, Allen and Steene 1997) over mud and rubble (Kailola *et al.* 1993). Eats larval stage of crustaceans, larger crustaceans, fish, and molluscs (Tucker 1999). Probably form aggregations during spawning.
Importance	Represents an important species for fisheries and aquaculture (Heemstra and Randall 1993). Considered vulnerable (Morris, Roberts and Hawkins 2000).

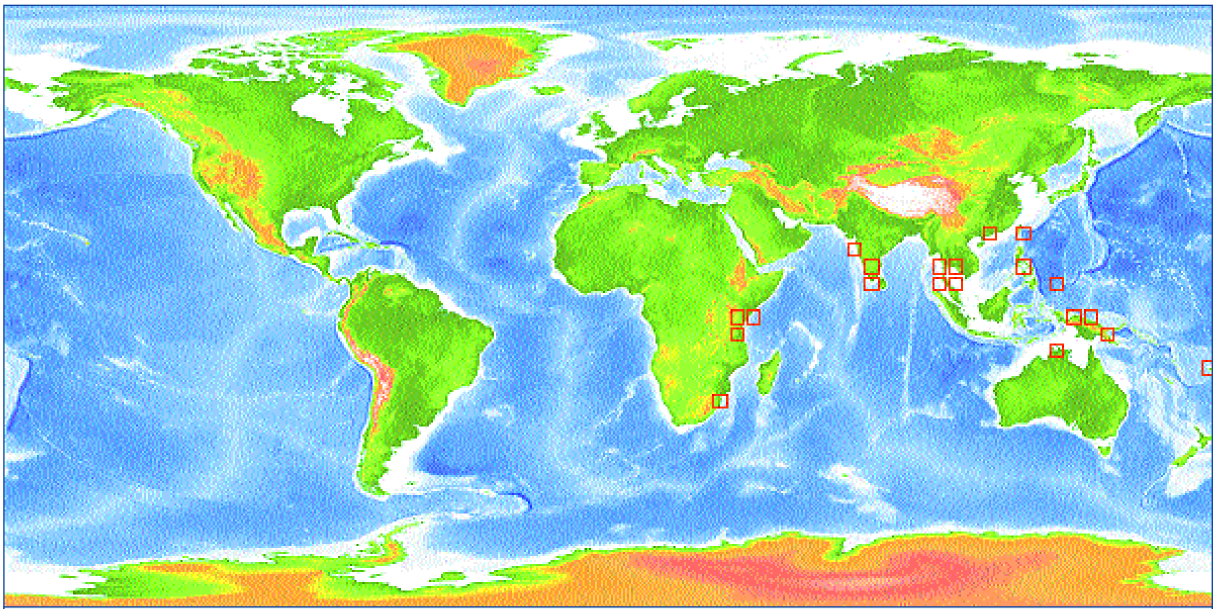


Figure 41. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Epinephelus coioides* (FishBase 2002)

Epinephelus malabaricus (Bloch and Schneider, 1801)

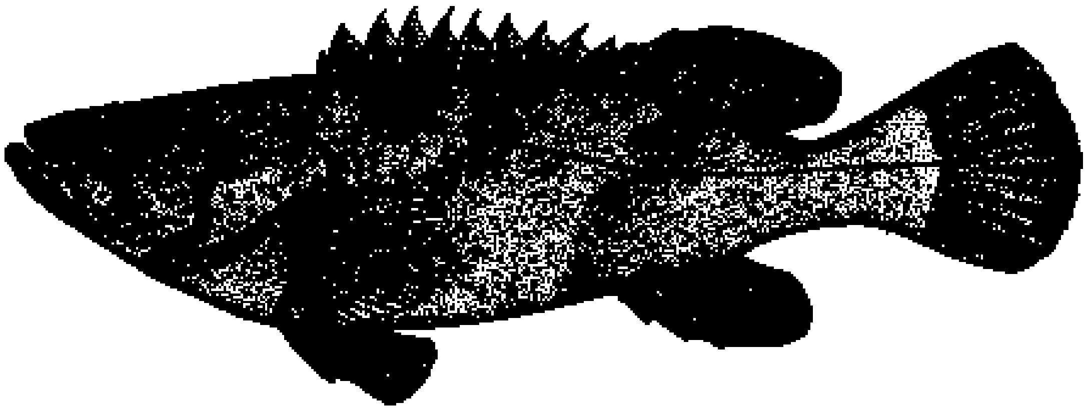


Figure 42. Malabar grouper (*Epinephelus malabaricus*) (FAO)

Table 30. Characteristics of the Malabar grouper (*Epinephelus malabaricus*) (FishBase 2002, modified)

Common name	Malabar grouper.
Size and age	Maximum length 234 cm TL (male/unsexed); maximum weight 150 kg.
Environment	Brackish and marine species, between shoreline and 150 m.
Climate and latitude	Tropical (35°N-35°S).
Resilience	No information available

Distribution	Indo-Pacific: Red Sea and East Africa to Tonga, north to Japan, south to Australia.
Biology and ecology	Found in a variety of habitats: coral and rocky reefs, tidal pools, estuaries, mangrove swamps and sandy/mud bottoms. Feeds primarily on fish and crustaceans, and occasionally on cephalopods (Lieske and Myers 1994).
Importance	Very important for fisheries because it is present in the Hong Kong live fish markets, and also for aquaculture (Lee and Sadovy 1998). Considered vulnerable (Morris, Roberts and Hawkins 2000).

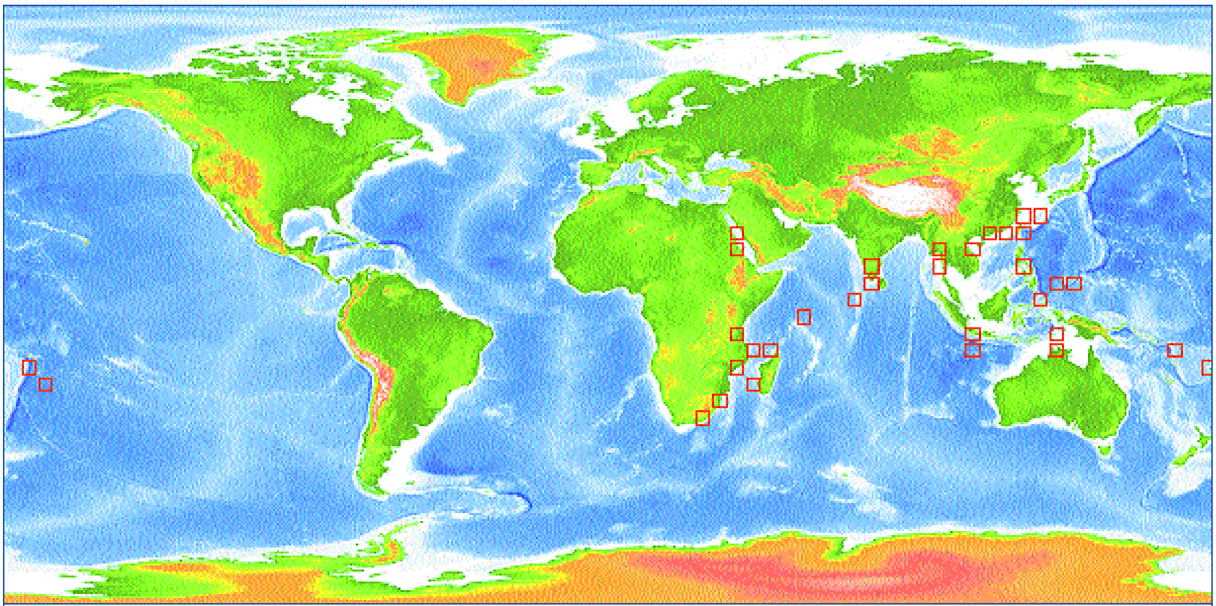


Figure 43. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Epinephelus malabaricus* (FishBase 2002)

Epinephelus areolatus (Forsskål, 1775)

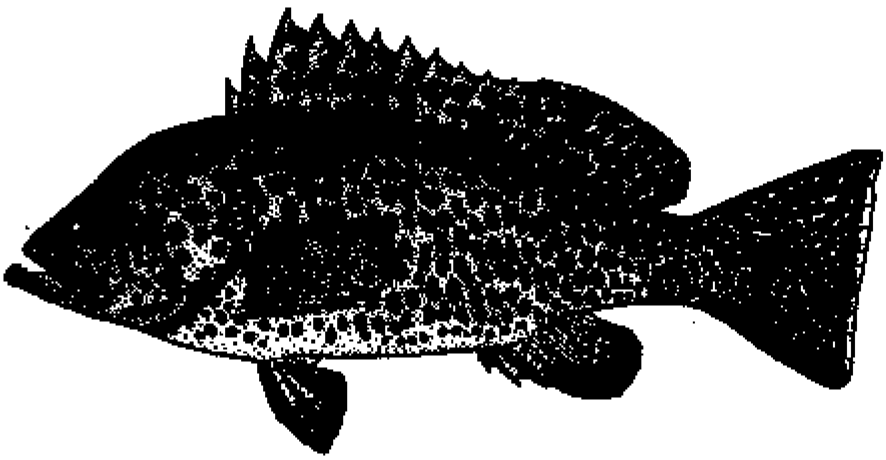


Figure 44. Areolate grouper (*Epinephelus areolatus*) (FAO)

Table 31. Characteristics of the Areolate grouper (*Epinephelus areolatus*) (FishBase 2002, modified)

Common name	Areolate grouper.
Size and age	Maximum length 47 cm TL (male/unsexed max. size); maximum weight 1.4 kg. Heemstra and Randall (1993) report maximum age of 15 years.
Environment	Marine, between 6-200 m.
Climate and latitude	Tropical (37°N-35°S).
Resilience	Population doubling time of 1.4-4.4 years, with medium resilience.
Distribution	Red Sea, Persian Gulf, and western Indian Ocean, south to Natal, South Africa Fiji, north to Japan, south to the Arafura Sea (Russell and Houston 1989) and northern Australia.
Biology and ecology	Found in sea-grass beds or on fine sediment bottoms near rocky reefs, dead coral, or alcyonarians (Heemstra and Randall 1993), in shallow continental shelf waters (Leis 1987). Feeds on fish and benthic invertebrates, primarily prawns and crabs (Randall and Heemstra 1991; Parrish 1987).
Importance	Commercially important species for fisheries and aquaculture. Considered a lower risk species (Morris, Roberts and Hawkins 2000).

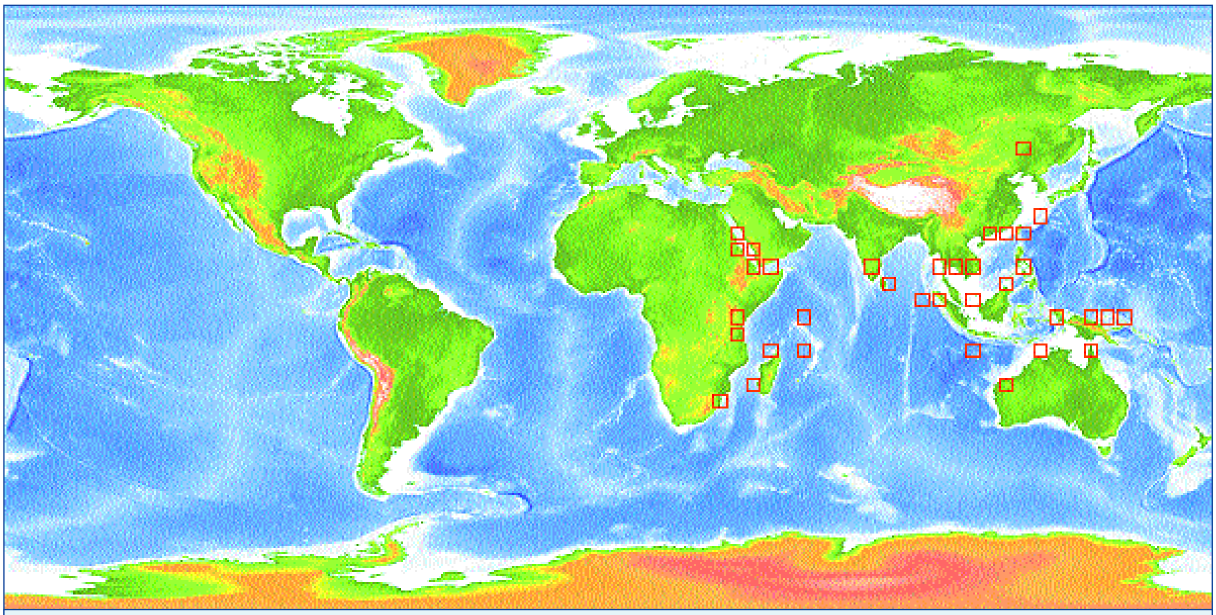


Figure 45. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Epinephelus areolatus* (FishBase 2002)

Epinephelus striatus (Bloch, 1792)

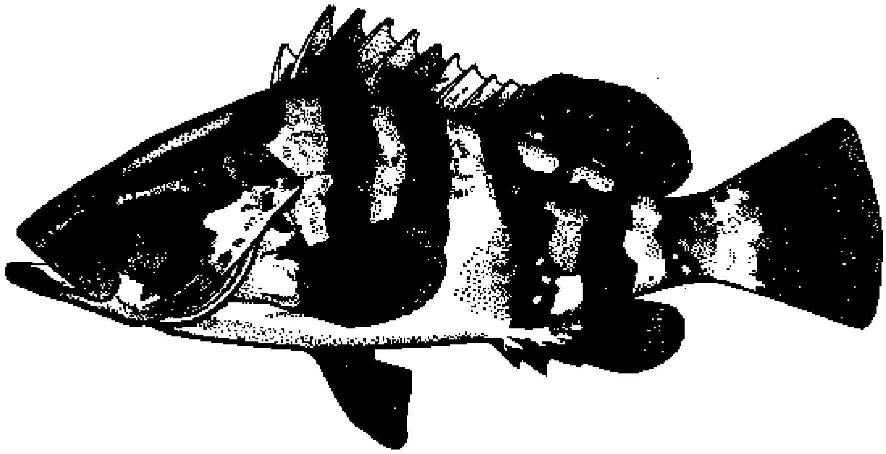


Figure 46. Nassau grouper (*Epinephelus striatus*) (FAO)

Table 32. Characteristics of the Nassau grouper (*Epinephelus striatus*) (FishBase 2002, modified)

Common name	Nassau grouper.
Size and age	Maximum length 122 cm TL (male/unsexed); maximum weight 25 kg; can live for 16 years.
Environment	Marine, down to 90 m.
Climate and latitude	Tropical (35°N-15°N).
Resilience	Population doubling time 4.5-14 years, with low resilience (Musick *et al.* 2000).
Distribution	Bermuda, Florida, Bahamas, Yucatan Peninsula and throughout the Caribbean to southern Brazil. In the Gulf of Mexico present only at the Campeche Bank off the coast of Yucatan, at Tortugas and off Key West (Heemstra and Randall 1993).
Biology and ecology	Close to reef, caves and in sea-grass beds (Lieske and Myers 1994). Solitary and diurnal. Eats fish (54%) and crabs (23%) and lesser amounts of other crustaceans and molluscs. Spawns near the new moon with up to 30 000 aggregating at certain spawning sites (Lieske and Myers 1994).
Importance	Represents the most important commercial grouper in the West Central Atlantic and for this reason is heavily fished without considering its vulnerability to overfishing. Considered endangered (Morris, Roberts and Hawkins 2000). In the market it is requested fresh, mostly between 2 to 10 kg (Smith 1978).

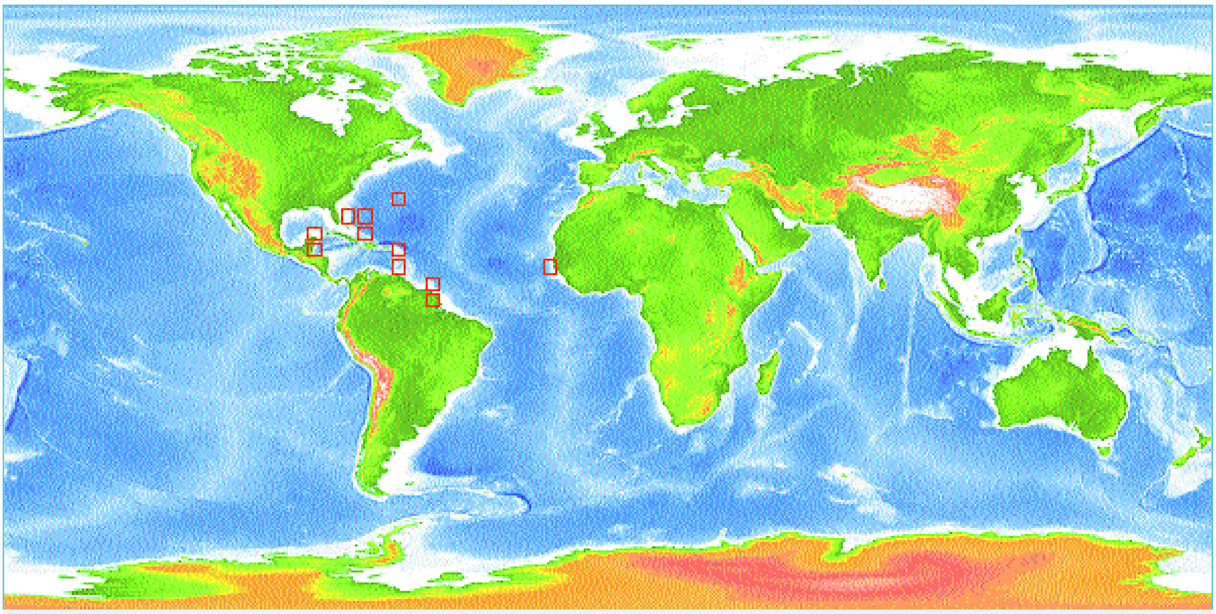


Figure 47. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Epinephelus striatus* (FishBase 2002)

Epinephelus fuscoguttatus (Forsskål, 1775)

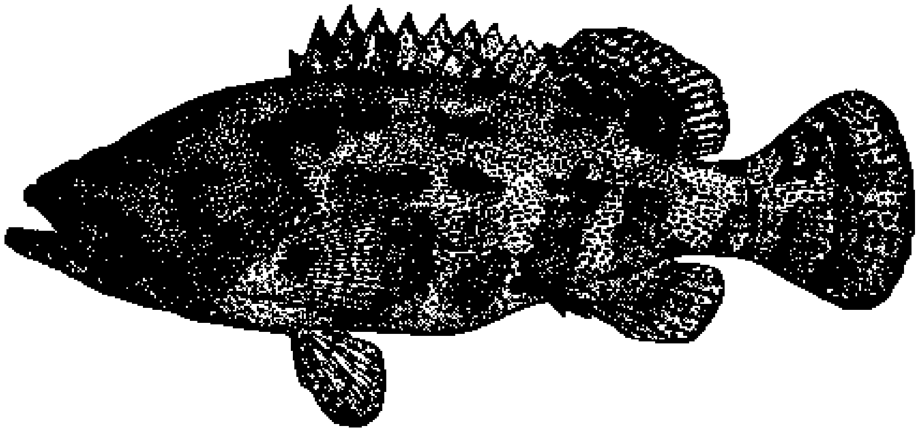


Figure 48. Brown-marbled grouper (*Epinephelus fuscoguttatus*) (FAO)

Table 33. Characteristics of the Brown-marbled grouper (*Epinephelus fuscoguttatus*) (FishBase 2002, modified)

Common name	Brown-marbled grouper.
Size and age	Maximum length 120 cm TL (male/unsexed); maximum weight 11 kg.
Environment	Marine.
Climate and latitude	Tropical, 35°N-35°S.

Resilience	Population doubling time 1.4-4.4 years with medium resilience (Heemstra and Randall 1993)
Distribution	Red Sea and along the east coast of Africa to Mozambique; east to Samoa and the Phoenix Islands, north to Japan, south to Australia.
Biology and ecology	Occurs in lagoon pinnacles, channels, and outer reef slopes, in coral-rich areas and with clear waters, and in sea-grass beds. Feeds on fish, crabs, and cephalopods.
Importance	Important in the Philippines, where it is cultured in experimental conditions and represented in the Hong Kong live fish markets (Leis 1987). Considered vulnerable (Morris, Roberts and Hawkins 2000)

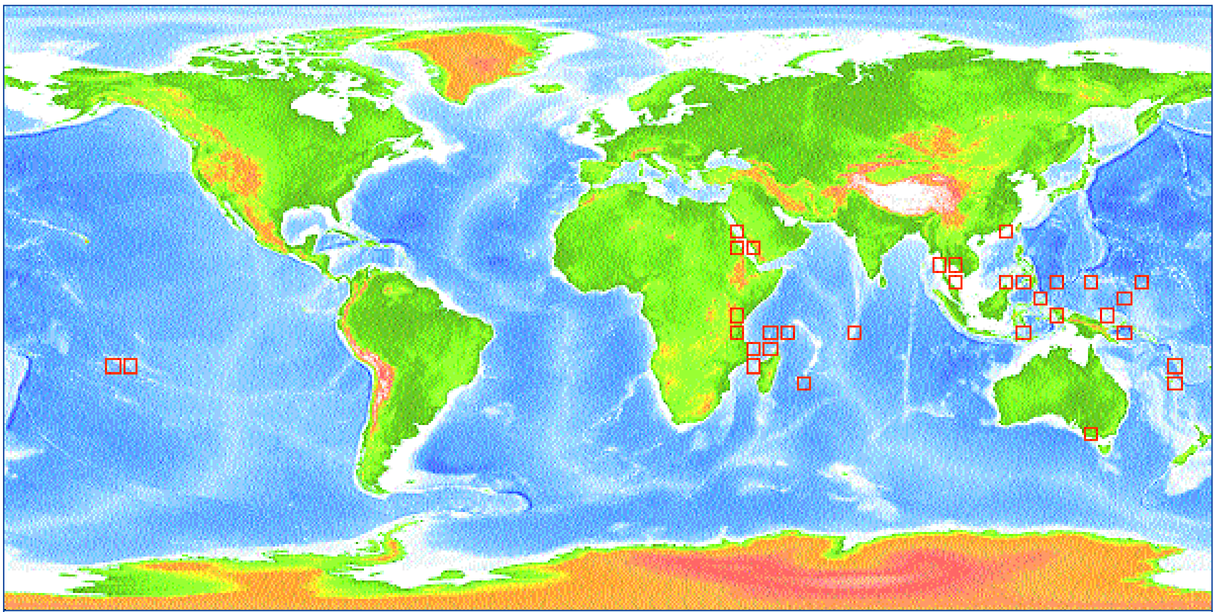


Figure 49. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Epinephelus fuscoguttatus* (FishBase 2002)

Epinephelus itajara (Lichtenstein, 1822)

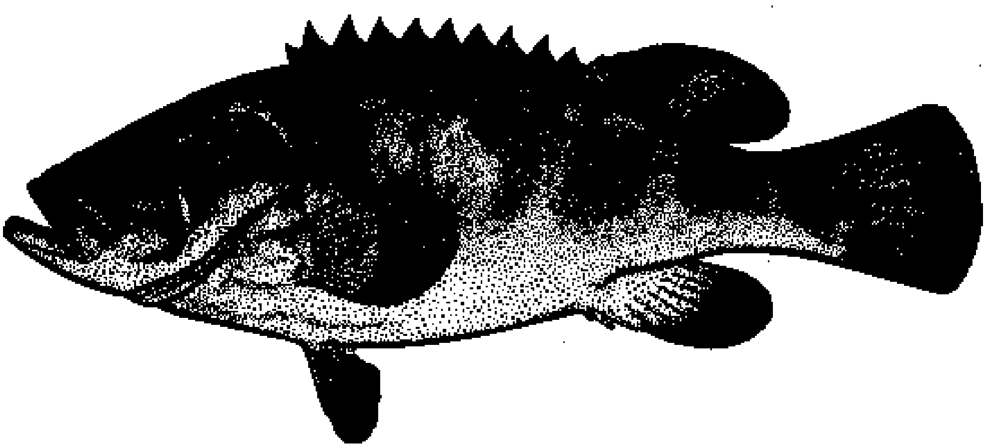


Figure 50. Goliath grouper (*Epinephelus itajara*) (FAO)

Table 34. Characteristics of the Goliath grouper (*Epinephelus itajara*) (FishBase 2002, modified)

Common name	Goliath grouper.
Size and age	Maximum length 250 cm TL (male/unsexed); maximum weight 455 kg.
Environment	Reef-associated; brackish and marine waters down to 100 m.
Climate and latitude	Subtropical (35°N-25°S).
Resilience	Population doubling time 4.5-14 years, with low resilience (Heemstra and Randall 1993).
Distribution	Western Atlantic: Florida, USA to southern Brazil and Eastern Atlantic, including Gulf of Mexico and the Caribbean.
Biology and ecology	Solitary species (Claro 1994) living in shallow, inshore areas such as estuaries (Cervigón *et al.* 1992), on hard bottoms such as rock, coral, or mud, in mangrove areas and brackish estuaries (Cervigón *et al.* 1992). Feeds on crustaceans, as well as turtles and fish, including stingrays.
Importance	It is an over fished species and critically endangered (UNEP classification A1d+2d) (Hilton-Taylor 2000). The meat is of excellent quality and it is sold fresh and salted.

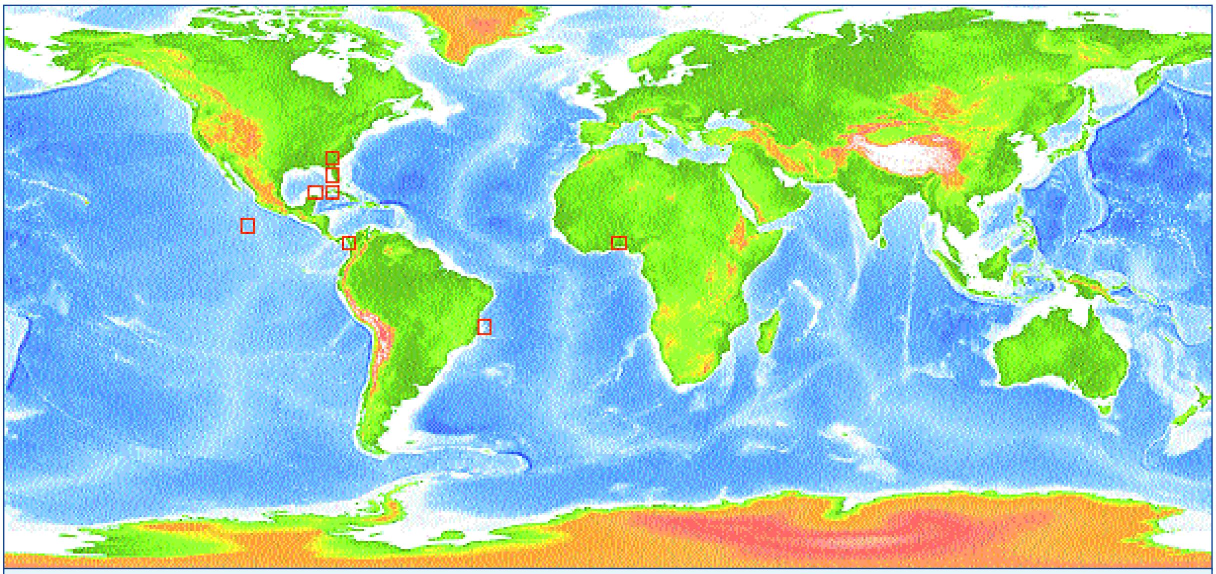


Figure 51. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Epinephelus itajara* (FishBase 2002)

Epinephelus akaara (Temminck and Schlegel, 1842)

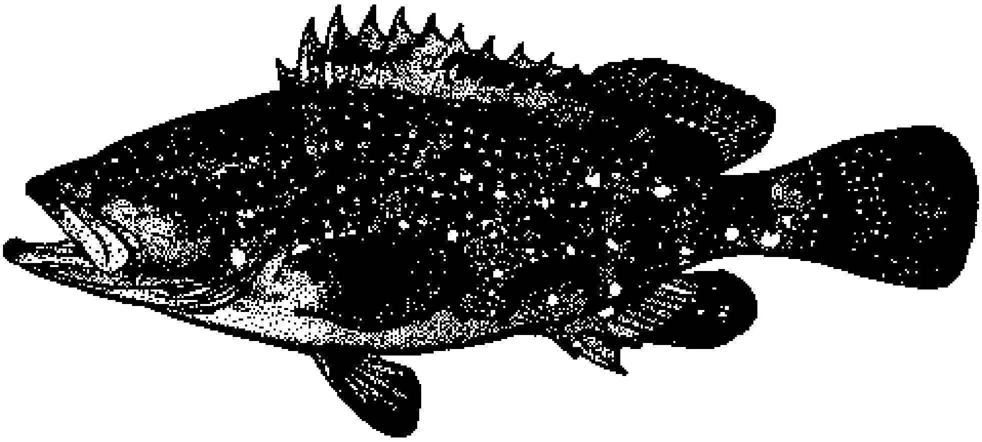


Figure 52. Hong Kong grouper (*Epinephelus akaara*) (FAO)

Table 35. Characteristics of the Hong Kong grouper (*Epinephelus akaara*) (FishBase 2002, modified)

Common name	Hong Kong grouper.
Size and age	Maximum length 53 cm TL (male/unsexed); maximum weight 2.5 kg.
Environment	Marine.
Climate and latitude	Tropical, 40°N-21°N.
Resilience	Population doubling time of 1.4 - 4.4 years and medium resilience (Heemstra and Randall 1993).

Distribution	Southern China, Taiwan Province of China, East China Sea, Korea, and southern Japan (Kyushu to about 38°N on both coasts of Honshu) (Heemstra and Randall 1993).
Biology and ecology	Lives over rock strata in reefs.
Importance	Highly prized food fish sold in Hong Kong live fish markets (Lee and Sadovy 1998); also important for aquaculture. Considered vulnerable (Morris, Roberts and Hawkins 2000).

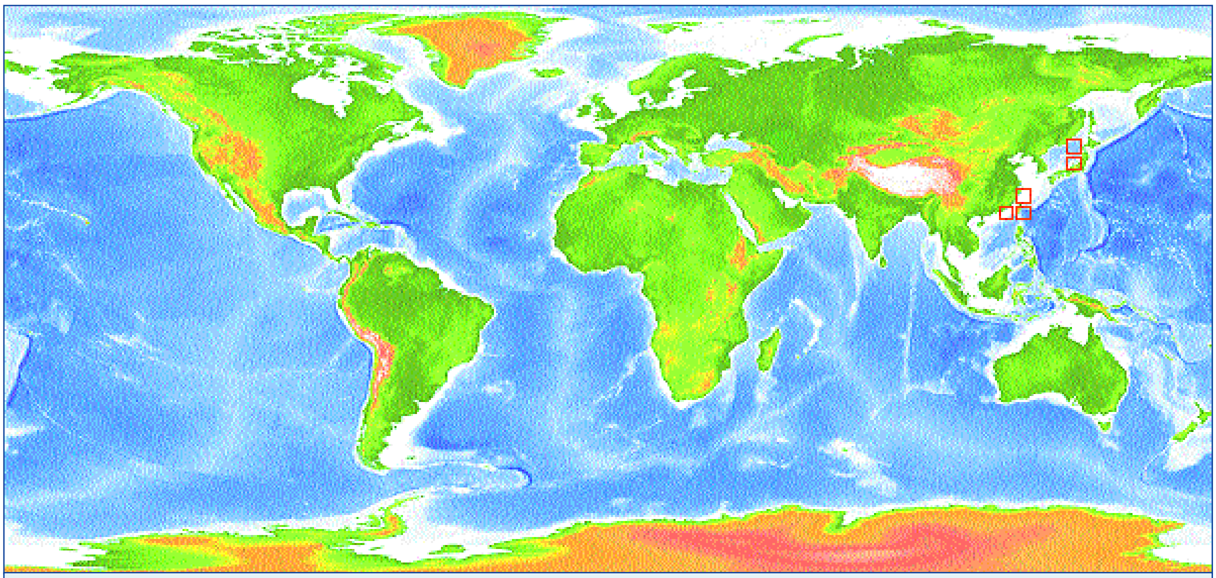


Figure 53. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Epinephelus akaara* (FishBase 2002)

Epinephelus tauvina (Forsskål, 1775)

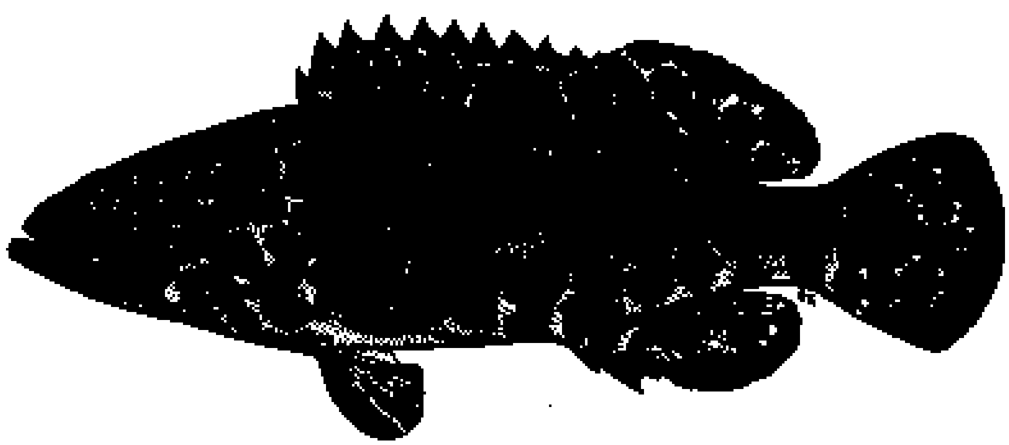


Figure 54. Greasy grouper (*Epinephelus tauvina*) (FAO)

Table 36. Characteristics of the Greasy grouper (*Epinephelus tauvina*) (FishBase 2002, modified)

Common name	Greasy grouper.
Size and age	Maximum length 107 cm TL (male/unsexed); maximum weight 12 kg.
Environment	Marine, living between 1 and 300 m (Allen and Steene 1988).
Climate and latitude	Subtropical, 35°N-36°S).
Resilience	Population doubling time 4.5-14 years, with low resilience (Heemstra and Randall 1993).
Distribution	Red Sea to South Africa and eastward to Ducie in the Pitcairn Group, north to Japan, south to New South Wales and Lord Howe Island.
Biology and ecology	Lives in clear water areas on coral reefs. Usually feeds on fish.
Importance	Important in fisheries and aquaculture and can be found in the Hong Kong live fish markets (Lee and Sadovy 1998). Considered a lower risk species (Morris, Roberts and Hawkins 2000).

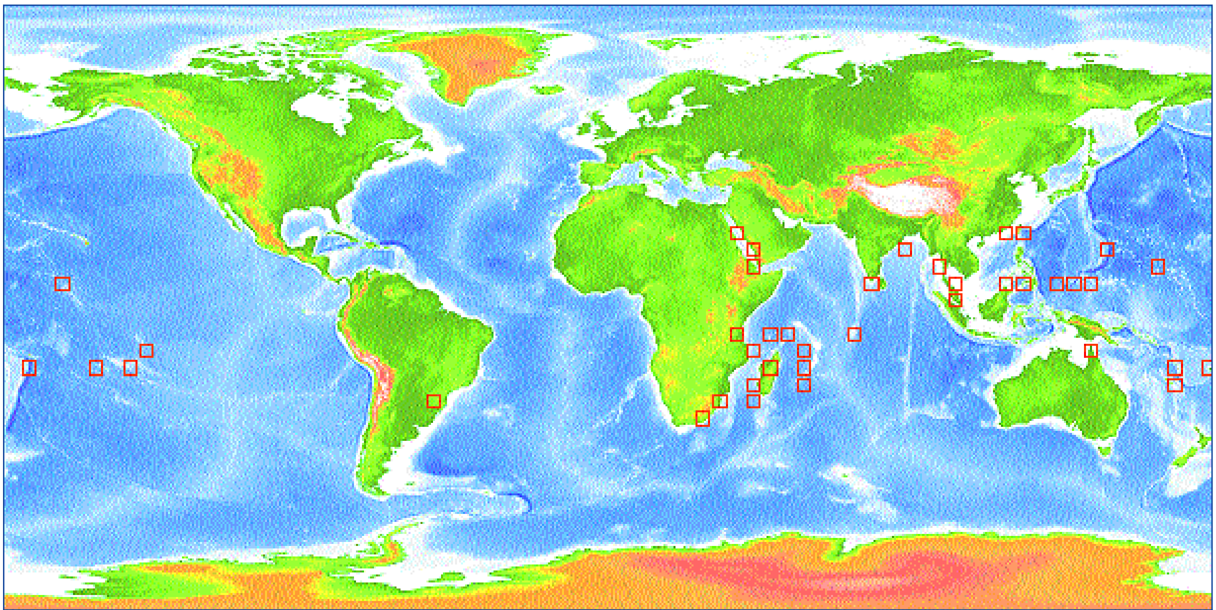


Figure 55. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Epinephelus tauvina* (FishBase 2002)

Fishery trends

Groupers are highly prized for the quality of their flesh, and most species fetch high market prices. This has led to overfishing in many areas, with species that are commercially favoured showing signs of declining numbers. A large proportion of the world's groupers are caught in artisanal fisheries, and even low-level artisanal fisheries can adversely affect stocks. Recreational fishing may also have significant impact on stocks; for example, the recreational fishery of groupers in Florida accounts for between 25% and 35% of the State's total grouper catch (Morris, Roberts and Hawkins 2000). The global catch of groupers showed a 68% increase from 100 724 tonnes in 1991 to 168 943 in 2000 (Figure 56).

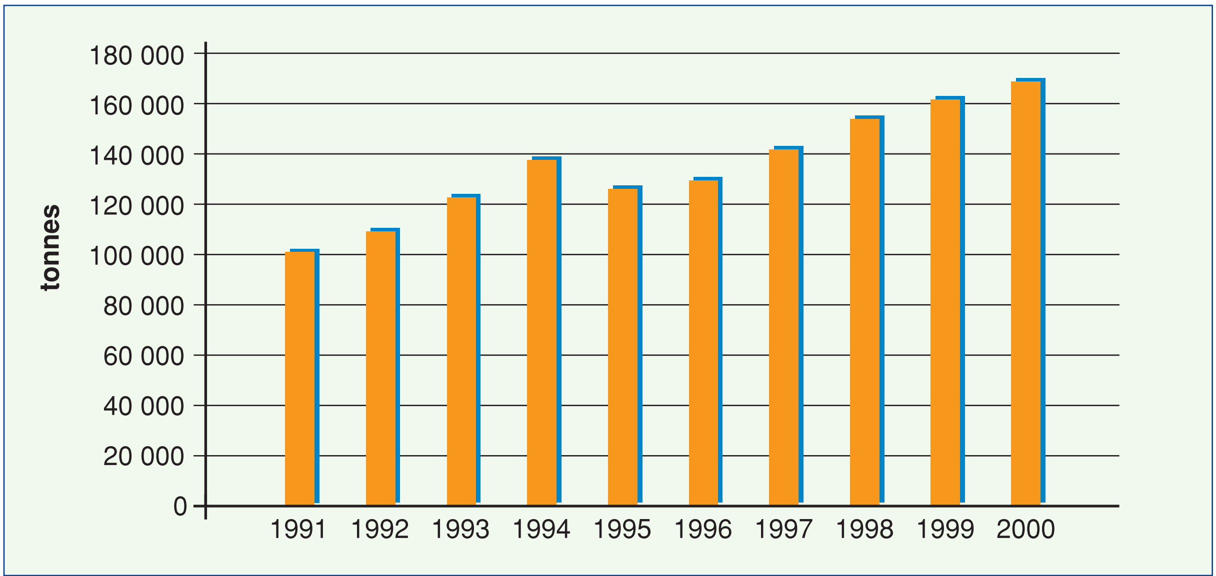


Figure 56. Trends in global grouper catch 1991-2000 (FAO 2002b)

The impact of intensive fishing is worsened by the K-selected life strategies of these genera, their tendencies to form predictable spawning aggregations, and their frequent 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 activity 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. 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).

With the rapidly developing economies of China and South-East Asia, the emergence of a wealthy class with substantial disposable incomes 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 (Sluka 1997; Johannes and Riepen 1995). 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 2000, most of the grouper catch was reported by developing countries (162 000 tonnes), with only 6 600 tonnes coming from industrialized nations. Asia was the leading continent with 125 100 tonnes, followed by North America (inc. Caribbean and Mexico) with 26 300 tonnes, Africa with 10 400 tonnes, South America with 5 000 tonnes, Oceania with 1 500 tonnes and Europe with 550 tonnes.

The leading area was the Western Central Pacific (47 000 tonnes), followed by Northwest Pacific (42 000 tonnes), Western Indian Ocean (27 000 tonnes) and Western Central Atlantic (23 000 tonnes) (Figure 57). In the same year, Indonesia was the leading country, followed by China. (Figure 58).

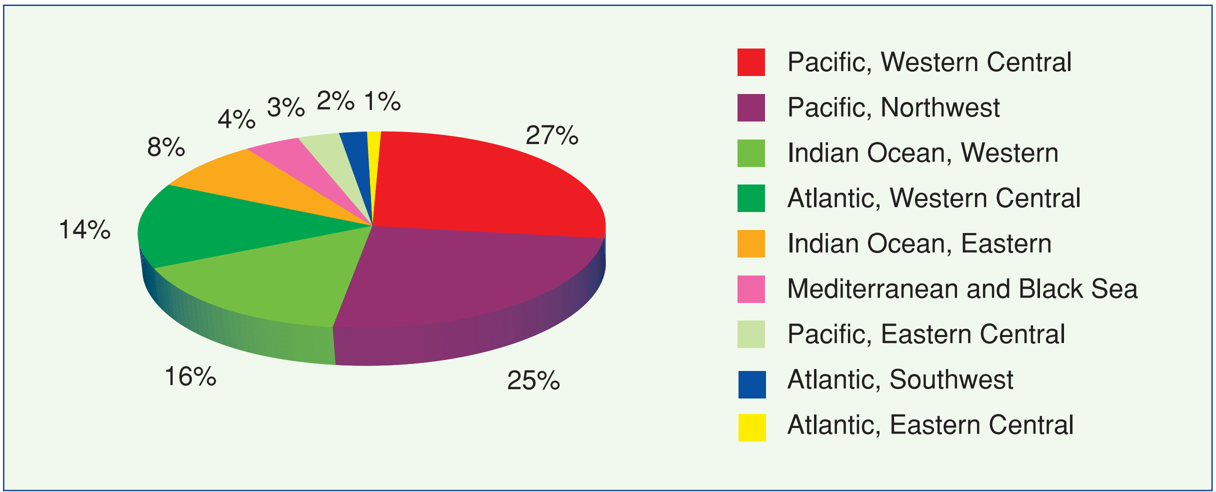


Figure 57. Global grouper catch by area in 2000 (FAO 2002b)

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).

The incredible prices paid for endangered species in Chinese and South-East Asian markets (in 1997 the red grouper – *E. akaara*, in Hong Kong fetched US$ 42/kg) (www.spc.org.nc/coastfish/news/LRF/5/15grouperHK.htm), mean that fishermen will go to great lengths in order to catch every fish, and this has already contributed to regional population crashes of species, including *E. akaara* and *E. striatus* (Morris, Roberts and Hawkins 2000; Sadovy 2001).

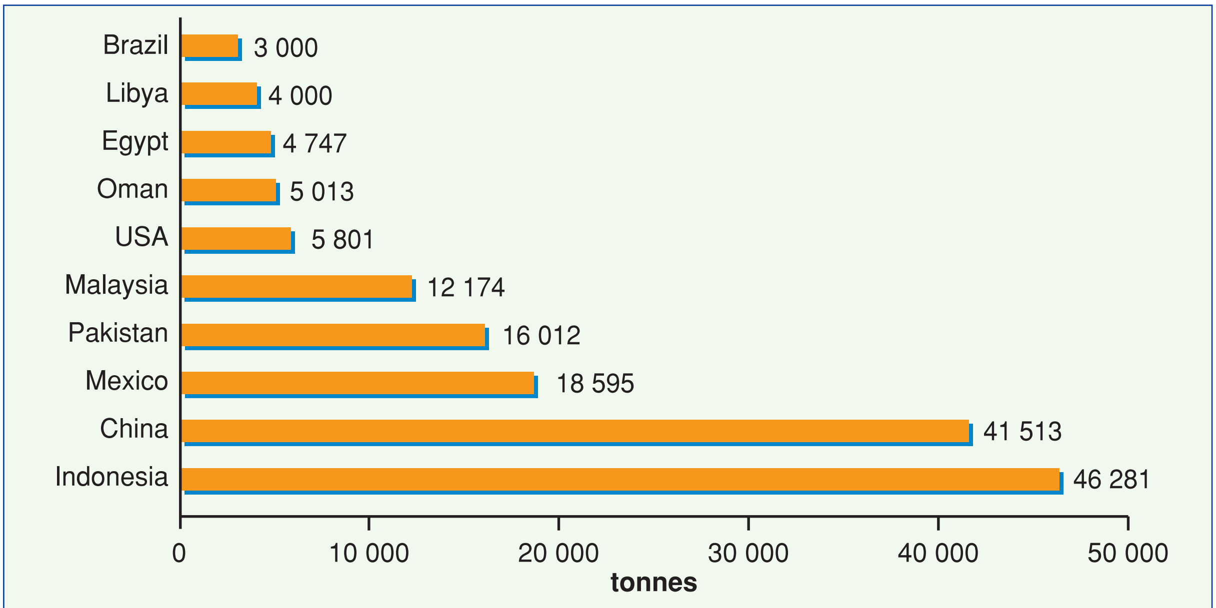


Figure 58. Capture fisheries for groupers: the top ten countries in 2000 (FAO 2002b)

Figure 59 shows the trend in the capture fishery for the Nassau grouper (*Epinephelus striatus*), for example. This species is caught in North and South America, mainly in the Bahamas (381 tonnes) and Cuba (50 tonnes), – 431 tonnes in 2000 in the entire Western Central Atlantic area. It represents one of the most important commercial groupers in this area and is heavily fished without any consideration being given to its vulnerability through overfishing; this species is considered endangered (Morris, Roberts and Hawkins 2000).

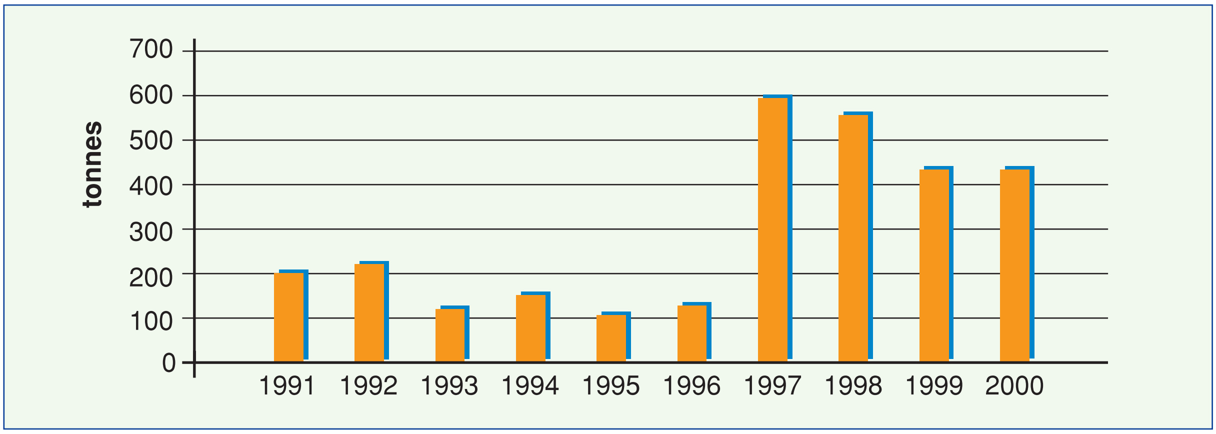


Figure 59. Trends in the global capture fishery for Nassau grouper (*Epinephelus striatus*) (FAO 2002b)

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). Grouper fishery trends suggest that a more holistic approach to establish the links between adults and juveniles is necessary.

Availability of "seed" for capture-based aquaculture

Generally, groupers spawn on offshore reefs where they form aggregations of tens of thousands of individuals, in a few specific locations. They produce pelagic larvae that may disperse over hundreds of kilometres in the course of 20-50 days and experience high density-independent mortality. Larvae, transported to near-shore nursery habitats settle as juveniles in sea-grass beds, mangroves, oyster reefs, and marshes (Coleman *et al.* 1999). For this reason grouper "seed" is mainly caught in coastal areas, particularly around sea-grass, mangrove and shallow brackishwater areas near river mouths and estuaries, as well as in tidal pools 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 windy weather (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 windy weather, which apparently caused the fish to be transported shoreward (e.g. Shenker *et al.* 1993; Dixon, Millich and Sugihara 1999).

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 a sobering thought to realize that the equivalent of the typical annual amount of seed produced in the hatcheries in the whole of SE Asia (excluding Taiwan Province of China), i.e. 20 000–80 000 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 are astonishing and strongly suggest crude and wasteful culture practices. To produce the regional estimate of 23 000 tonnes of table-size live fish from culture annually (roughly 10 000 tonnes of which is included in the regional live reef fish trade (LRFT) volume provided above), about 60 million seed fish are needed (Sadovy 2000). The trade in grouper "seed" throughout South East Asia is complex and extensive (Figure 60).

The major destinations of the trade routes for grouper "seed" are Hong Kong, China and Taiwan Province of China, while the major sources are the Philippines, Thailand, and, to a lesser extent, Indonesia, Malaysia and Taiwan Province of China. Two-thirds of the production from Taiwan Province of China is based on the grow-out of hatchery reared fry; this country also exports both hatchery produced seed, and imports and re-exports capture-based "seed".

Some of the trade is probably illegal because of a concern in some countries about keeping adequate numbers for local use, or the importation of disease with the seed (e.g. between Malaysia and Hong Kong, Taiwan Province of China and Thailand; from Johore (Malaysia) through Singapore to Taiwan Province of China; between Myanmar and Thailand; and from Taiwan Province of China to the People's Republic of China). Some trade from Viet Nam to the People's Republic of China may also be illegal, but this can not be substantiated.

Other identified minor trade routes are from Indonesia and the Philippines to Brunei Darusallam, and from the People's Republic of China to Hong Kong. Sri Lanka has supplied seed to Hong Kong. Seed also enters the People's Republic of China from Thailand and Taiwan Province of China through Hong Kong. In this survey, the roles of Singapore, Sri Lanka, Japan and the Republic of Korea have not been included, although they play a minor part in various aspects of the live reef fish trade. The absence of detailed trade data makes it difficult to fully evaluate trade routes (Sadovy 2000).

Catching methods for "seed" material

Grouper "seeds" are collected using several different methods, depending on their location (Table 37). Catching 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 (Figure 61); artificial reefs; fish attractors; tidal pools; and chemicals. The sizes of grouper "seed" caught and traded vary between 1-25 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).

For *Epinephelus coioides* and *E. malabaricus*, "seed" sizes are categorized as follows:

- un-scaled post-larvae, which are transparent or reddish, averaging 1 to 2.5 cm total length;
- scaled fry, which have begun to darken, ranging from around 2.5 to 7.5 cm (often measured from the eye to the caudal peduncle);
- fingerlings, from 7.5 to 12.5 cm (Johannes and Ogburn 1999).

Some grouper "seed" collection methods are more damaging than others. Clearly destructive are methods that result in high mortality, involve high levels of bycatch, cause damage to the fish habitat and/or result in monopolization of the local fishery by a few individuals. These include scissor nets and fyke nets, which are already banned in some areas. Lift nets are also destructive, particularly in terms of bycatch. Gango, miracle holes, fish shelters (with or without a boat), and lift nets (types of 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).

Figure 60. Major trade routes for grouper "seed" throughout Southeast Asia

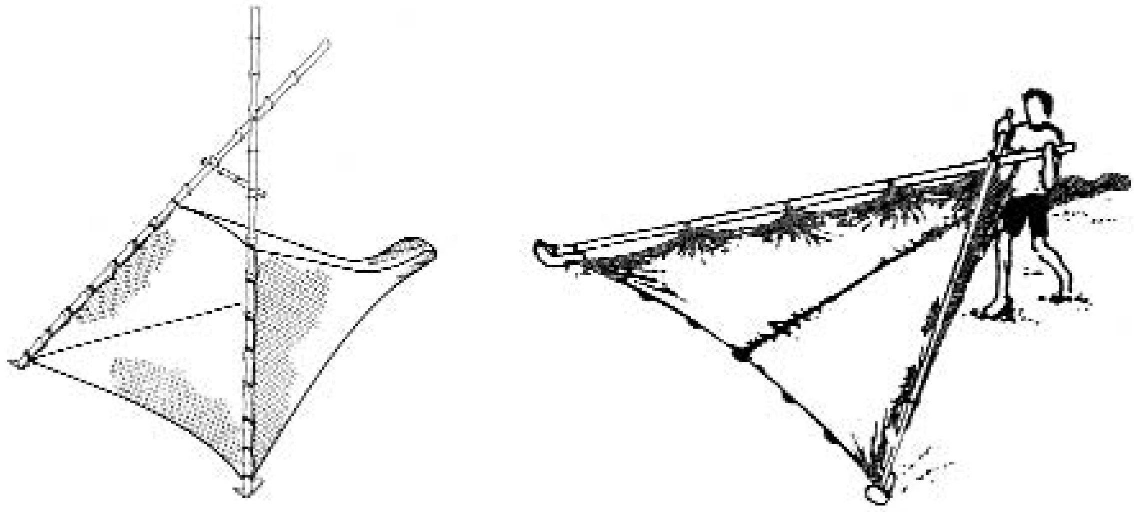


Figure 61. Example of catching method: scissor nets (Source: FAO)

Table 37. Local "seed" collection methods for the capture-based aquaculture of groupers (Johannes and Ogburn 1999; Ahmad 1997; Sadovy 2000)

LOCATION	GEARS USED	DESCRIPTION	FISH SIZE
Philippines	Gango (Fish nests)	Conical pile of waterlogged, crisscrossed wood or of rocks, sometimes in combination, together with old car tyres, PVC pipe cuttings, bamboo sections, or other shelter materials. 5–10 m^2, with a 2–3 m diameter or 2.5-3 m x 2-3 m base and 0.5–1.5 m height. The largest may be 5 m diameter at the base.	2-15 cm
Philippines People's Republic of China Thailand	Fish shelters	Formed by hanging brushes, nets, or clusters of grasses, leaves or other materials. Used with or without lights.	1-3 cm
Indonesia Malaysia Philippines People's Republic of China Taiwan Province of China Viet Nam	Fish traps	Vary in shape and size, and in mesh size. The trap frame is made of wood, metal or bamboo.	2-25 cm

LOCATION	GEARS USED	DESCRIPTION	FISH SIZE
Philippines Thailand Viet Nam	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.	1-15 cm
Indonesia Malaysia Philippines People's Republic of China Taiwan Province of China Thailand Viet Nam	Hook and line		>7.5 cm
Philippines Thailand	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.	2.5-15 cm
Philippines	Miracle hole	Shallow holes are excavated on tidal flats. Sometimes the wall of the hole is built up with rocks.	5-10 cm
Malaysia	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 the sandy sea bottom between two poles.	2-2.5 cm

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% mortality rate, while artificial aggregators such as *Temarang* (also used in Malaysia) cause 3% 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% and

80% 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 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% 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% 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).

According to Tucker (1999) "seed" groupers should be shipped in 4 mm (or thicker) food-grade polyethylene bags filled with oxygen and water in equal parts. The bags should be kept at the spawning temperature or a few degrees lower, in an insulated, rigid container. Juvenile groupers can be shipped in bags at 120g/l at 23°C with oxygen for up to 12 hours.

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%), 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 (www.spc.org.nc/coastfish/News/LRF/5/15GrouperHK.htm), the survival rate for imported fry is low, at 10-20%.

Trends in aquaculture production

Groupers are cultured in many Southeast Asian countries, including Indonesia, Malaysia, Philippines, Taiwan Province of China, Thailand, Hong Kong, the southeast of the People's Republic of China, and Viet Nam – as well as other parts of the tropics in the south eastern USA and Caribbean. Grouper culture is also undertaken in India, Sri Lanka, Saudi Arabia, Republic of Korea and Australia.

Eating live seafood (i.e. seafood that is kept alive until immediately before cooking) is a strong tradition among consumers along the southeast coast of China. In recent years this culture has spread to neighbouring countries with large Chinese populations, including Taiwan Province of China, Singapore, Hong Kong, Malaysia and Thailand. The Chinese word for "fish" has the same pronunciation as the word for "plentiful" and is an important symbol in traditional Chinese agricultural society. Fish are important components of all dinner receptions. In Hong Kong 95% of all restaurants are Chinese, and most serve live seafood (Chan 2000b).

Despite their popularity, only 15-20% 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 (for example in Taiwan Province of China and Kuwait) (Tucker 1999). It is difficult to get accurate statistics on farmed grouper production because 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 are not differentiated. Data shown in this report have come from FAO and other sources.

Figure 62 shows recent trends in grouper aquaculture production. These statistics consist of official national returns to FAO based on commercial, artisanal and subsistence aquaculture, and are considered to be underestimates.

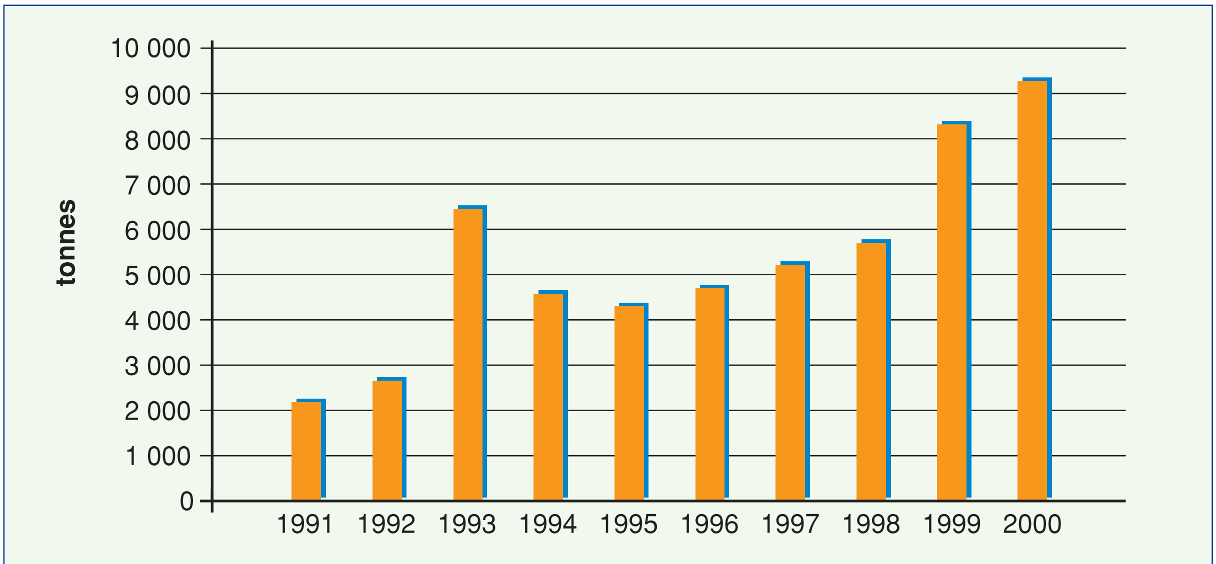


Figure 62. Trends in global grouper production by aquaculture (FAO 2002a)

According to Figure 63, 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 SE Asia are reported by Sadovy (2000) to be far higher, at 23 000 tonnes; however, about 20% of this production may be based on hatchery produced fry, while the remainder is from wild seed. According to this author, China is the main producer (8 300 tonnes). 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.

Figure 64 shows data on the top ten grouper producing countries in 2000. According to official statistics, Taiwan Province of China was the leading producer, with nearly 5 100 tonnes (54% of the global total).

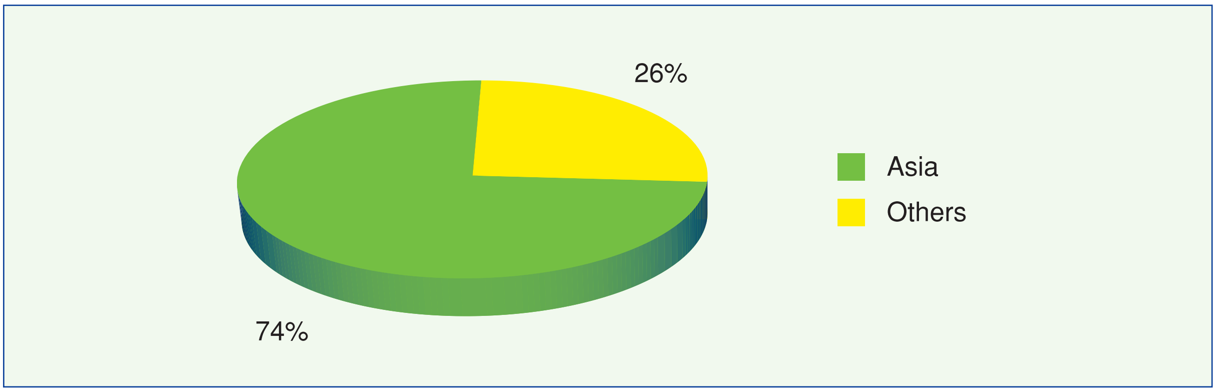


Figure 63. Grouper aquaculture production by continent in 2000 (FAO 2002a)

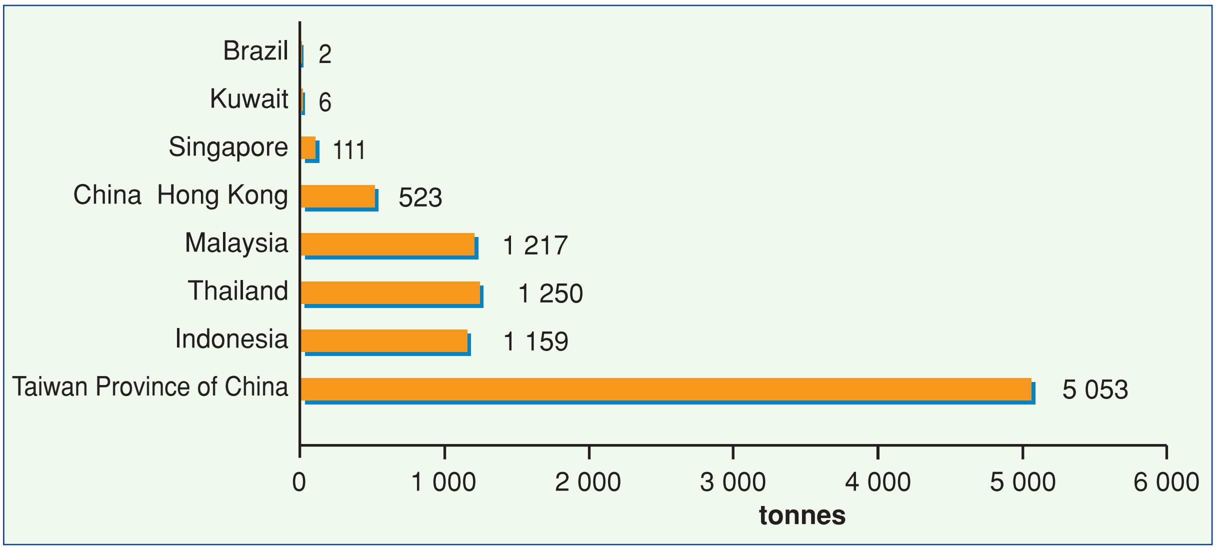


Figure 64. Top ten farmed grouper producers in 2000 (FAO 2002a)

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, Hong Kong and Taiwan Province of China.

Table 38 presents data for grouper culture production made by various authors, compared with FAO data. The absence of homogeneity is obvious. Accurate information is difficult to obtain; hence the production estimates vary significantly, depending on the authors' sources. Their data comes from interviews, questionnaires, literature reviews and pers. comm. gathered by each author. When information is collated from a variety of sources, e.g. government offices, private producers, traders, middlemen, exporters and importers, and from fishing communities, academic institutions and hatcheries, etc., it is not easy to obtain reliable estimates.

Table 38. Estimates of farmed grouper production in selected countries

LOCATION	YEAR	Tonnes	REFERENCE
Hong Kong	1990	3 000	Li (1999)
	1999	1 000	Sadovy (2000)
	2000	523	FAO (2002a)
India	2000	200	James (2000)
Indonesia	1999	1 000	Sadovy (2000)
	2000	1 159	FAO (2002a)
Republic of Korea	1999	50-100	Young Don (2002)
	2000	data unavailable	FAO (2002a)
Malaysia	1994	600	Ali and Ali (1999)
	1994	800	Biusing, Phillips and Cabandan (1999)
	1995	513	Komilus and Biusing (2002)
	1995	834	Ali (1998)
	1997	798	Subramanian (2002)
	2000	1 217	FAO (2002a)
Philippines	1997	496	Somga, Somga and Reantaso (2002)
	1997	654	Bureau of Agricultural Statistics (1997)
	1998	33	Agbayani (2002)
People's Republic of China	1997	2 500 (Guangdong Province)	Yongzhong (2002)
	1999	8 300 (Total China)	Sadovy (2000)
Singapore	1995	121-444	Mee (1999)
	2000	111	FAO (2002a)
Taiwan Province of China	1990	1 000	Chu (1999)
	1995	1 500	Chu (1999)
	1999	7 000	Cesar *et al.* (2000)
	2000	5 053	FAO (2002a)
Thailand	1992	965	Ruangpanit (1999)
	1994	710	Ruangpanit (1999)
	2000	800	Lin (2001)
	2000	1 250	FAO (2002a)
Viet Nam	1999	Total fish production 5 000 (mostly groupers)	Sadovy (2000)

Culture systems

There are many different systems used for the culture of groupers worldwide, although there appears to be an agreed set of stages: nursery, transition, and on-growing. Grouper "seed" has to 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 nursing, 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 catching. The density may range from 100 to 150 fish/m^2, e.g. a net of 2 x 2 x 2 m would hold 400-600 fingerlings. Sorting is undertaken every week, and stock sampling every 15 days. 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). The net cage is 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.seafdeec.org.ph). According to Agbayani (2002), 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 mm to 35 mm. The optimum stocking density averages 120 fish/m^3. Growth to marketable size (600-800 g) takes approximately 8 months, with survival rates of 50% or less (Leong 1997). Groupers can grow to 600 g in 12 months, to 1 kg within 18 months, and to 2 kg within 24 months (Tucker 1999).

A summary of the conditions for grouper culture is presented in Table 39 (www.seafdeec.org.ph). For brackish water culture, ponds are 800 to 1 600 m^2, or from 6 400 m^2 to 12 800 m^2. The pond depth should at least be 1-2 m, with a level pond bottom to allow for easy harvest.

Table 39. Summary of the characteristics of grouper culture systems

Culture	Temperature (°C)	Salinity (ppt)	DO_2 (ppm)	Dimension	Stocking density	Culture period
Nursery	24-31	21-41	4.9-9.3	2x2x2 m	400-600	1 month
Transition	24-31	21-41	4.9-9.3	5x5x5 m	1 100	2-3 months
Grow-out	24-31	21-41	4.9-9.3	3x3x2.5 m 4x4x2.5 m 10x10x3 m	120/m^3	8 months
Pond	24-31	21-41	4.9-9.3	800-12 800 m^2	5 000/ha	14 months

Feeds and feeding regimes

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. Fry and fingerlings are fed with mysids and small shrimp for a couple of days post-catching 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.

A suitable starter feed for groupers should contain 50-60% high quality protein, 12-16% fat, ≤15% carbohydrate, ≤3% fibre and ≤16% ash (Tucker 1999). Lower quality feeds may result in higher feed conversion ratios (FCR) and possibly slower growth. In grow-out cages, fish are fed at 10% of body weight daily, while those in nursery cages are given about 8% of body weight/day.

The optimum feeding rate in production cages is 5% of body weight and the range of FCRs achieved is 0.94 to 7.5:1, depending on the feed and the species (Pillay 1995; Boonyaratpalin 1997; Bombeo-Tuburan, Kanchanakhan and Chinabut 2001). According to Agbayani (2002) FCRs average between 2.5-2.8:1 for dry pellets and 6.3:1 for trash fish. When temperatures fall below 15°C, the fish do not feed. Some species of groupers feed indifferently during the day or night; others (for example *Epinephalus akaara*) favour feeding just before sunset. Cultured red groupers exhibit a special feeding behaviour: the fish can be trained to know when to expect food. When they sense the sound of trash fish being chopped or a wooden plank being knocked, they gather at the cage edge. As groupers are of a suspicious nature, they watch for food but do not move. However, if one fish attempts to approach the food, all the fish will immediately attack it violently, sometimes injuring themselves in the process. Groupers usually eat one to three pieces of minced trash fish, then disperse. No attempts are ever made to eat any food which falls to the net bottom, no matter how hungry the groupers might be. Owing to this special feeding behaviour, groupers are generally reared with seabream which act as scavengers and stimulate the groupers to feed (Boonyaratpalin 1997). This is also a means of preventing water pollution due to decaying 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 Chinabut (2001) fared significantly better in terms of final length and total production than when fed other diets (live tilapia, formulated diet). The quality of the bycatch used may be estimated from the efficient feed conversion achieved (1:1 on dry basis), significantly better than the formulated diet, which had an FCR of 2.8. Using bycatch, 47% of the harvest weighed more than 400 g, with only 14% being classified as <200 g.

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, either 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% of their dietary composition (Tacon 1995). 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% 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 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 the linkage between the mad-cow disease (BSE) and CJD in humans.

Fish health and disease

Bondad-Reantaso, Kanchanakhan and Chinabut (2001) presented a review of the diseases affecting cultured groupers in SE Asia, which listed the various grouper species affected, together with the symptoms, and the country where the infection was found. The contents of this section of the report are principally drawn from that source. A summary of the major pathogens reported to have affected farmed groupers is given in Table 40.

Gram-negative bacteria, ectoparasitic protozoans and monogeneans are among the most important pathogens for groupers. The lethal “sleepy grouper disease”, seen in Singapore, was probably caused by a virus introduced with wild juvenile groupers that had been imported for cage farming (Tucker 1999). Other viral pathogens and diseases include “golden eye disease”, “red grouper retro-virus”, “spinning grouper disease”, and “viral nervous necrosis”. Pasteurellosis has been a major disease in young red-spotted groupers in Japan. Infestations of the gills, eyes and skin by monogenean or protozoan parasites, which feed on blood, skin and mucus have been reported for Western North Atlantic species (Tucker 1999).

The most common disease encountered in captive groupers is “red boil disease” characterized by inflammation, haemorrhage and ulceration of skin and musculature. Infection by the protozoan parasite *Cryptocaryon irritans* causes loss of scales and skin, especially in the head region (Pillay 1995; Bondad-Reantaso, Kanchanakhan and Chinabut 2001). Chou *et al.* (1999) found a positive correlation between increased environmental stress (transport, crowding, temperature and catching stresses, and exposure to heavy metal pollutants) and increased mortality; this correlation has also been documented in cases involving infectious haematopoietic necrosis virus (IHNV) and infectious pancreatic necrosis virus (IPNV).

A new grouper infection, caused by a marine leech (*Zeylanicobdella arugamensis*), has been documented in the Philippines, Sri Lanka, the Malay Peninsula, Singapore, India, Indonesia and along the coast of Queensland, Australia (Cruz-Lacierda *et al.* 2000). A didymozoid trematode (*Gonapodasmius epinepheli*) infection was also observed in pond-reared orange-spotted grouper (*E. coioides*) in the Philippines. Didymozoids are parasitic trematodes, usually living in pairs of capsules in the connective tissue of the fins, skin, mouth cavity, operculum, muscles, stomach, intestine, liver or other organs of fish (Cruz-Lacierda *et al.* 2001).

Table 40. Specific pathogens of cultured groupers in Southeast Asia

VIRUSES

Nodaviruses

➔ Viral Nervous Necrosis (VNN)
➔ Spinning grouper disease
➔ Paralytic syndrome

Iridoviruses

➔ Sleepy grouper disease
➔ *GIV-1*
➔ *GIV-2*
➔ Blister disease

Reovirus

➔ Red grouper disease

Astro-like virus

➔ Golden eye disease
➔ Lymphocystis
➔ Herpes virus

BACTERIA

➔ Bacteriosis caused by *Pseudomonas* sp.
➔ *Pasteurella piscicida*
➔ Red boil disease
➔ *Flexibacter* sp.
➔ *Vibrio* spp.
➔ *Vibrio harveyi*
➔ *Vibrio parahaemolyticus*

PARASITES

Protozoa

➔ *Brooklynella* sp.
➔ *Cryptobia* sp.
➔ *Cryptocaryon irritans*
➔ *Ribosyphidia* sp.
➔ *Scyphidia* sp.
➔ *Trichodina* sp.
➔ *Vorticella* sp.

Myxozoa

➔ *Myxosoma* sp.
➔ *Ceratomyxa* sp.
➔ *Sphaerospora* sp.

Microspora

➔ *Pleistophora* sp.

Monogenea

→ *Benedenia* sp.
→ *B. ephinepheli*
→ *Cycloplectanum epinepheli*
→ *Dactylogyrus* sp.
→ *Gyrodactylus* sp.
→ *Haliotrema* sp.
→ *Neobenedenia girellae*
→ *Megacotyloides epenepheli*
→ *Megacotyloides* sp.
→ *Tareenia* sp.
→ *Diplectanum* sp.
→ *Pseudorhabdosynochus* sp.
→ *Dactylogyridae*
→ *Diplectanidae*

Trematoda

→ *Allopodocotyle* sp.
→ *Cardicola*
→ *Ectenurus* sp.
→ *Gonapodasmius* sp.
→ *Helicometrina nimia*
→ *Lecithochirium neopacificum*
→ *Pearsonellum* sp.
→ *Prosorhynchus pacificus*
→ *Prosorhynchus* sp.
→ *Pseudopecoeloides* sp.
→ *Pseudometadena celebesensis*
→ *Stephanostomum* sp.
→ *Didymozidae*

Crustacea

→ *Caligus* sp.
→ *Ergasilus borneoensis*
→ *Gnathia* sp.
→ *Lepeoptheirus* sp.
→ *Thebius* sp.

Nematoda

→ *Contracaecum* sp.
→ *Echinocephalus* sp.
→ *Raphidascaris* sp.

Cestoda

→ *Tetraphyllidae*
→ *Cestoda* sp.

Achantocephala

→ Acanthocephalus sp.

Hirudinea

Apart from some virus problems in Southeast Asia, very little is known about the impact of major diseases, which may go beyond the direct effects of observed mortalities and production losses. Disease outbreaks, and the subsequent losses they create, affect all levels of aquaculture activity and are profoundly felt by small-scale farmers, who represent the backbone of many rural communities. In Asian aquaculture, the livelihoods of farmers are threatened through reduction in food availability, loss of income and employment, social upheaval and increased vulnerability (Bondad-Reantaso, Kanchanakhan and Chinabut 2001).

Harvesting systems

Unlike the case with some other species reared in capture-based aquaculture systems, e.g. tunas or yellowtails, the harvesting of groupers is relatively simple (Figure 65). 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.

Figure 65. Harvesting of groupers in a brackishwater pond in Chonburi, Thailand
(Photo: NACA)

Marketing

Currently, grouper culture is almost entirely dependent upon the trade in high quality reef fish (Figure 66), owing to the relatively high production costs (due to poor survival rates in hatcheries; shortage of wild seed in many areas; poor survival in grow-out; and high feed costs, etc.). The market is dominated by the trade through Hong Kong, which supplies the local market and is also destined for re-export to mainland China. Grouper market requirements are determined primarily by the tastes and customs of people of Cantonese origin.

The following factors are of particular significance:

- red colour is associated with luck and happiness. Thus groupers with red pigmentation command a premium price;
- the fish are commonly steamed whole. Firm flesh with low fat content and fine grained skin are therefore preferred;
- demand is closely related to cultural and economic cycles. Demand is greatest around Chinese New Year (January/February), and during the Wedding Season. During the rest of the year, demand may be related to economic prosperity and the business cycle;
- demand is dynamic. Different species become fashionable at different times;
- *vivier* boats (with tanks for live fish transportation) are large and discrete marketing units.

Figure 66: Groupers being sold in a fresh fish market in the Philippines
(Photo: Nelson A. Lopez)

A threshold level of production is required to access the services of a *vivier* boat; isolated producers may be highly dependent upon them to sell their production. The power of the *vivier* to control farm-gate prices is therefore considerable. Prices vary enormously. Aquaculturists should be cautious when basing their economic estimates on some of the higher published values. There are large premiums on some of the less common and larger species, and for the more desirable species there is a significant premium on size, with larger fish often commanding double the unit price of smaller, same species fish. This is related to the demand for fish of at least 1-2 kg in the high class restaurant market sector. The premium on size is much less for those species in lower demand in this sector. Industry mark-ups are high, reflecting the high transportation and storage costs for live fish. On the other hand, wholesale prices for *Epinephelus malabaricus*, *E. tauvina, E. coioides*, and *E. fuscoguttatus* may vary from US$ 20/kg in Hong Kong to US$ 5-15/kg in Thailand, depending on quality and size (www.enaca.org/grouper/research/economics/1999/04/market.htm).

Figure 67 shows that the farm-gate global value of the aquaculture production of groupers reported to FAO increased from US$ 17.3 million in 1991 to US$ 64.3 million (98% in Asia) in 2000. However, Sadovy (2000) estimated that the retail value of the groupers reared in Southeast Asia alone was US$ 575 million, assuming an average retail value (Hong Kong prices) of US$ 25/kg.

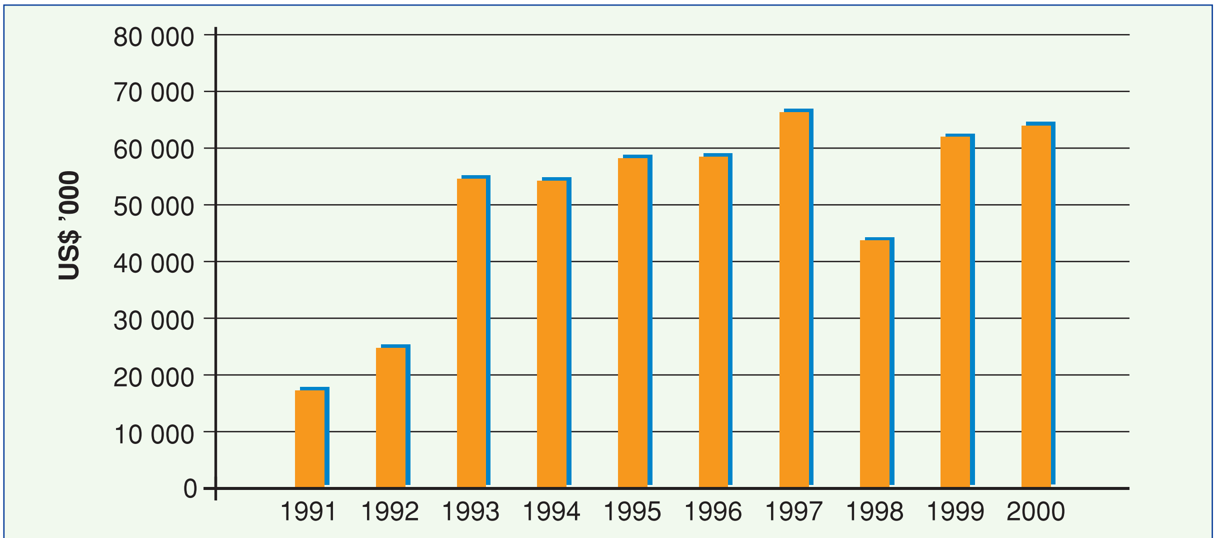


Figure 67. Global value of grouper aquaculture (1991-2000) (FAO 2002a)

Figure 68 shows the value of the production of the top ten producers, according to FAO (2002a). The most important market areas are in China and Hong Kong but there is also significant demand for groupers in Japan, Taiwan Province of China and Singapore. Demand is also increasing in the Republic of Korea, Thailand and Malaysia.

The value of the production of some specific cultured grouper species in 2000 was as follows: greasy grouper (*E. tauvina*) aquaculture production reached US$ 6.9 million in Malaysia and US$ 5.5 million in Hong Kong in 2000; areolate grouper (*E. areolatus*) production in Hong Kong was US$ 1.7 million, while orange-spotted grouper (*E. coioides*), cultured in Kuwait, was valued at US$ 39 000 (Fishstat Plus 2002).

An important characteristic of the grouper market is ethnic consumer preference. The domestic demand in Brunei Darussalam is quite small; most of the local people believe that eating groupers is not healthy, especially for those suffering from asthma. However, groupers are one of the most favoured fish for Chinese people.

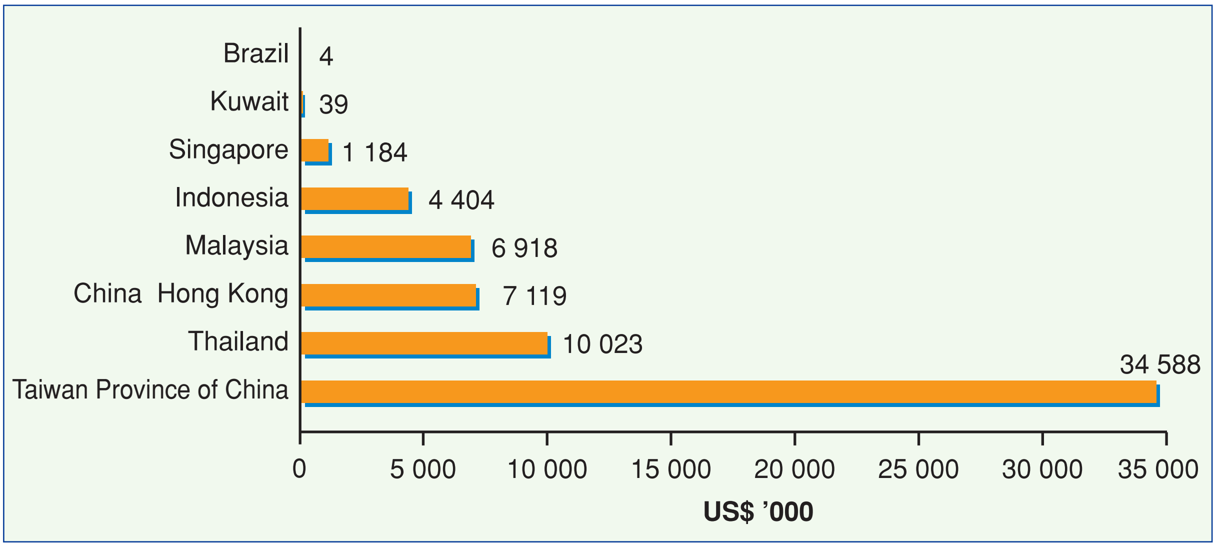


Figure 68. Top eight countries in grouper aquaculture by value in 2000 (FAO 2002a)

Exports of grouper to Hong Kong are by air or by live *vivier* boats. While air freighting is worthwhile for high-value grouper species, boat transport is more convenient and cost effective for the more ordinary, lower-value species. Comparisons between these two modes of transporting live groupers to Hong Kong were presented in a study by Pudadera, Hamidand and Yusof (2002). Live groupers transported by air were marketed direct to the Hong Kong wholesale auction market, where they fetched an average price of US$ 21/kg; groupers transported by a *vivier* boat were purchased at the farm price, i.e. the Hong Kong buyer collected live groupers directly from the farm and purchased them for US$ 8.50/kg. The average net profit (after deducting the transportation fees) for the live groupers shipped by air was US$ 8.73/kg, while those collected from the farm by *vivier* boat had a margin of US$ 7.78/kg.

An example of the production costs for grouper culture from a study by Boonchuwong and Lawapong (2002) is shown in Table 41. In this survey, the average revenue per farm was US$ 9 800, with an average net profit of US$ 4 800. Since approximately 85% of the total production of cage cultured groupers in this study was exported, the marketing system was geared to the requirements for live fish export. The marketing process consisted of a number of steps, with few traders being involved because the output had to be distributed quickly. The major agencies involved in the marketing system were brokers, collectors (wholesalers) and exporters. The average marketing costs of collectors were US$ 1.06/kg or US$ 1.20/fish and the average net profit was US$ 0.52/kg. The marketing costs of a collector averaged US$ 878/month, with a profit of US$ 432. For an exporter, marketing costs averaged US$ 4 000/month and the net profit was US$ 3 775/month. Exporters get the highest returns of all the traders involved in the live grouper marketing system, since they have better access to foreign marketing information and price movements. They also have to be compensated for the risks which they take, for example the death of valuable live fish during transport. However, with respect to the marketing system as a whole, farmers get the highest share, which accounts for nearly 55.5% of the price the foreign importers have to pay. From the traders share the exporters get the highest share (37%), whereas the collectors get only 7.5%.

Groupers are also traded internationally in whole, dressed, fresh/chilled or frozen forms. In Southeast Asia fresh/chilled groupers are sold through supermarkets, mainly in the dressed form. The USA is a potential market for processed groupers, both in dressed and fillet forms. Large quantities of groupers are already imported into the USA, mainly from the central American countries (Pawiro 2002). Grouper imports by the USA in 1999 (FAO 2002d) were 4 170 tonnes in fresh or chilled form and 330 tonnes frozen, with a total value of US$ 17.7 million.

Exports from India, Indonesia and Thailand are predominantly frozen fillets (Pawiro 2002). According to this author, prices of chilled grouper fillets from Latin America range from US$ 3.50 to 5.80/kg. Frozen groupers are exported to the USA for US$ 1.50-2.00/kg for whole/gutted fish and US$ 3.00-3.50/kg for fillets.

Production of frozen groupers peaked in 1993 but, by 1999 had returned to 1990 levels (Figure 69). In 1999 the leading producers of frozen groupers were in North America (Mexico: 7 603 tonnes), followed by Asia (Philippines: 3 720 tonnes), Africa (Senegal: 326 tonnes), and Europe (Greece: 130 tonnes).

Table 41. Production costs of farming groupers in Thailand

ITEMS	AVERAGE PRODUCTION COSTS (US$)				
	PER FARM	PER CAGE	PER FISH	PER KG	%
FIXED COSTS	**735**	**183**	**1.05**	**0.87**	**14.7**
Depreciation	160	40	0.23	0.19	3.2
Opportunity cost	575	143	0.82	0.68	11.5
VARIABLE COSTS	**4 264**	**1 066**	**6.09**	**5.08**	**85.3**
Seed	1 200	300	1.72	1.43	24.0
Feed	2 856	714	4.08	3.40	57.1
Repairs	80	20	0.12	0.10	1.6
Others	128	32	0.18	0.15	2.6
TOTALS	**4 999**	**1 250**	**7.14**	**5.95**	**100**

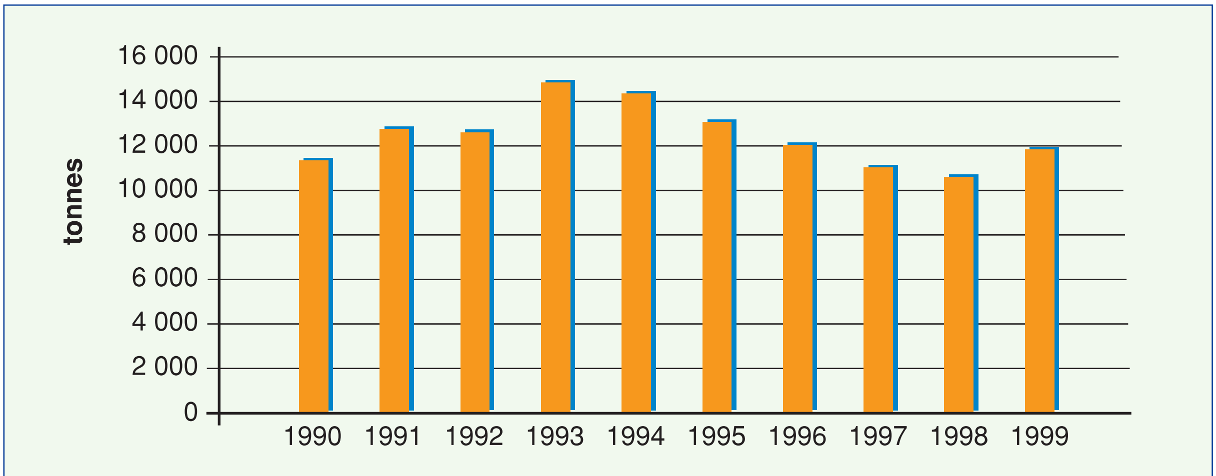


Figure 69. Production of frozen groupers (FAO 2002d)

Although the authors of this report have made extensive efforts to analyse and consolidate market information and data, it is felt that there are gaps in the data presented here. All potential investors should undertake their own detailed evaluation of the prospective markets.

The principle reasons for the inconsistency of the data are:

- It is difficult to make accurate or useful assessments of any type of aquaculture without specific reference to local prices and circumstances. These are extremely variable throughout the Southeast Asian region.
- Production parameters, especially survival rates, have a wide range and/or are poorly reported.

Conclusions

The future development of the capture based aquaculture of groupers is likely to be influenced by several key requirements:

- The development of markets which are outside the specialist live markets.
- Production methods that can produce groupers at significantly lower costs so that "non-live" markets can be accessed at a profit.
- The development of better catching and culture methods to reduce the excessive wastage of juveniles, resulting in additional hatchery production.
- The development of better feeds to move away from the reliance on trash fish.
- Better management and control of diseases.
- The development of new culture systems that allow culture activities to be moved beyond congested and polluted port areas.

Groupers have high quality flesh, and are recognized worldwide as a good eating fish. With the demise of many traditional white fish sources, a high quality marine fish will always find a market. Grouper products could be well placed to access the market for white fish fillets, which are popular in both the USA and Europe.

chapter 5

TUNAS

5

TUNAS

Introduction and species identification

Tunas belong to Actinopterygii (ray-finned fishes), order Perciformes, family Scombridae which contains about 32 species and subspecies. Two species of special commercial interest to fisheries and capture-based aquaculture are considered in this report: the northern bluefin tuna *Thunnus thynnus* [two subspecies were recognized by Gibbs and Collette (1967): *Thunnus thynnus thynnus* (Linnaeus, 1758) in the North Atlantic and *Thunnus thynnus orientalis* (Temminck and Schlegel, 1844) in the North Pacific] and the southern bluefin tuna *Thunnus maccoyii*. The Integrated Taxonomic Information System (www.itis.usda.gov) states that *Thunnus orientalis* was "formerly included in *Thunnus thynnus* (Linnaeus, 1758) as a subspecies". However, Collette *et al.* (2001) support treating this Pacific taxon as a full species (*Thunnus orientalis*), quite separate from the Atlantic taxon (*Thunnus thynnus*). Our report follows the old approach.

The Atlantic subspecies of the northern bluefin tuna (*Thunnus thynnus thynnus*) is found from Labrador and Newfoundland south into the Gulf of Mexico and the Caribbean Sea and is also known off Venezuela and Brazil in the Western Atlantic; in the Eastern Atlantic it occurs from the Lofoten Islands off Norway south to the Canary Islands and the Mediterranean Sea. There is also a population off South Africa. The Pacific subspecies (*T. thynnus orientalis*) is known from the Gulf of Alaska to southern California and Baja California in the Eastern Pacific; in the Western Pacific it occurs from Sakhalin Island in the southern Sea of Okhotsk south to the northern Philippines.

Northern bluefin tuna are highly migratory, according to Annex I of the 1982 Convention on the Law of the Sea (www.oceanlaw.net/texts/losc.htm; FAO 1994). A pelagic species, it can be found seasonally coming close to the shore and can tolerate a wide range of temperatures. The fish shoal by size, sometimes together with albacore, yellowfin, bigeye, skipjack, etc. The northern bluefin tuna is one of the most important species in Japanese fisheries; its meat is utilized fresh for "*sashimi*" and, due to massive overfishing, it has become increasingly rare (Muus and Nielsen 1999).

During the spawning season, adult southern bluefin tuna (*Thunnus maccoyii*) migrate to tropical seas, off the west coast of Australia, up to 10°S. It is considered a highly migratory species (FAO 1994). Within 100 years its population will be below 500 mature individuals if the current exploitation continues (Matsuda *et al.* 1998). This species is highly prized in Japan for the "*sashimi*" market and specialized fisheries for *sashimi*-quality fish have been recently developed in New Zealand. Overfishing is severe for *T. maccoyii* and it was suggested the species should be declared an endangered species under the Endangered Species Act (1992) and listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Tables 42-43 summarize the characteristics of the northern and southern bluefin tunas, while Figures 70-73 illustrate their appearance and geographical location.

Thunnus thynnus (Linnaeus, 1758)

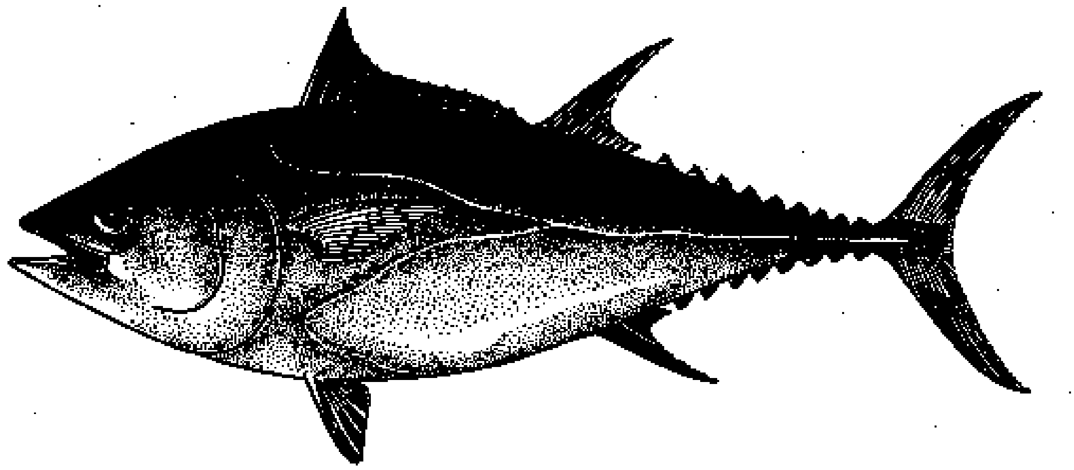


Figure 70. Northern bluefin tuna *(Thunnus thynnus)* (FAO)

Table 42. Characteristics of the northern bluefin tuna *(Thunnus thynnus)* (FishBase 2002, modified)

Common name	Northern bluefin tuna.
Size and age	Maximum size of 458 cm TL (male/unsexed) and maximum weight 684 kg. Life span approximately 15 years.
Environment	Brackish and marine species.
Climate and latitude	Subtropical climate (70°N-40°S).
Resilience	Minimum population doubling time of 4.5-14 years, with low resilience (Collette 1999).
Distribution	The Atlantic subspecies is found from Labrador and Newfoundland south into the Gulf of Mexico and the Caribbean Sea to Venezuela and Brazil in the Western Atlantic; in the Eastern Atlantic from the Lofoten Islands off Norway south to the Canary Islands and the Mediterranean Sea. There is also a population off South Africa. The Pacific subspecies from the Gulf of Alaska to southern California and Baja California in the Eastern Pacific; in the Western Pacific from Sakhalin Island in the southern Sea of Okhotsk south to the northern Philippines.
Biology and ecology	This pelagic species can be found seasonally coming close to shore, and can tolerate a wide range of temperatures; it feeds on small schooling fishes (anchovies, sauries, hakes), squids and red crabs.
Importance	This is one of the most important species in Japanese aquaculture and fisheries; its meat is utilized fresh for *sashimi* and also canned (Frimodt 1995); it has become rare because of massive overfishing (Muus and Nielsen 1999).

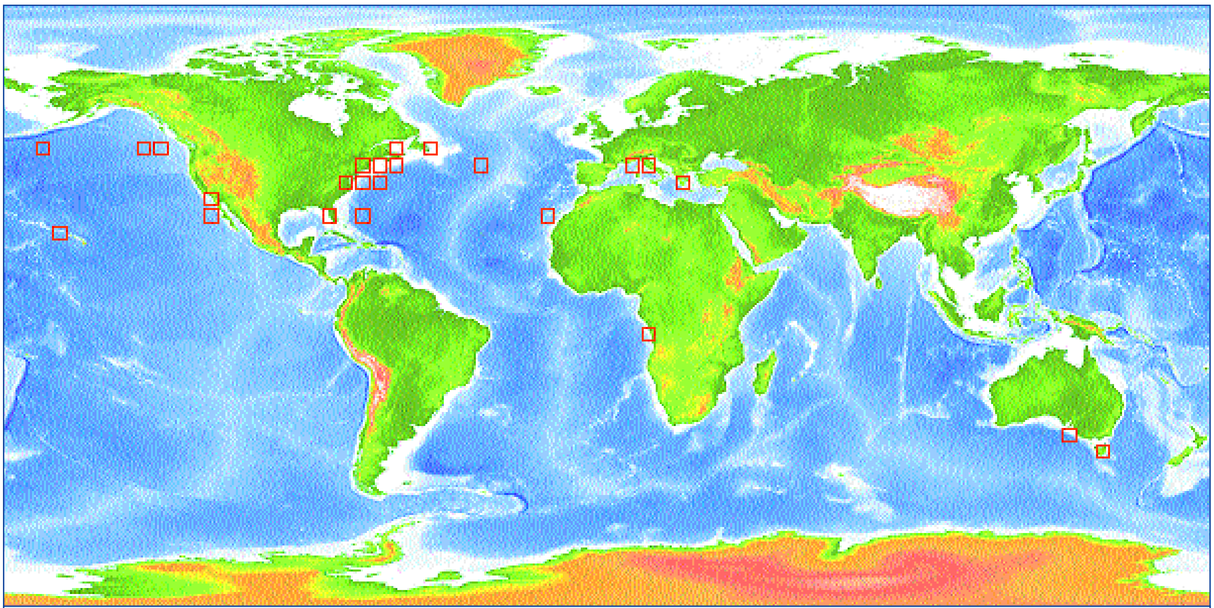


Figure 71. **Zoological sites sampled for geographic distribution (indicated by the red squares) of *Thunnus thynnus*** (FishBase 2002)

Thunnus maccoyii (Castelnau, 1872)

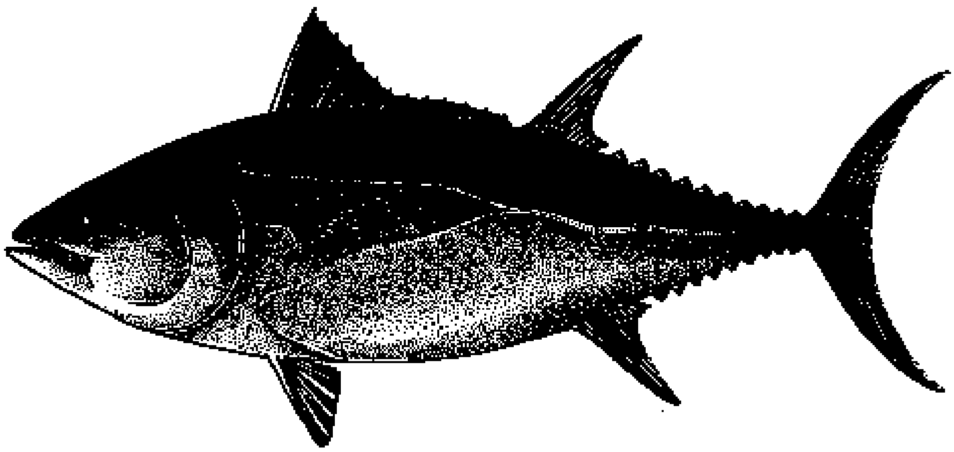


Figure 72. Southern bluefin tuna *(Thunnus maccoyii)* (FAO)

Table 43. Characteristics of the southern bluefin tuna (*Thunnus maccoyii*) (FishBase 2002, modified)

Common name	Southern bluefin tuna.
Size and age	Male specimens reach 245 cm FL and a maximum weight of 260 kg; maximum life span 20 years.
Environment	Pelagic, marine species.
Climate and latitude	Subtropical climate (5-20°C) between 10°S and 60°S.

Resilience	Doubling time of 4.5-14 years and low resilience (Collette and Nauen 1983).
Distribution	It can be found in the Southern Hemisphere in temperate and cold seas, mainly between 30° and 50°S, to nearly 60°S. At spawning season, adults migrate to tropical seas off the west coast of Australia, up to 10°S.
Biology and ecology	By maturity, most Southern bluefin tuna lead an oceanic, pelagic existence (Kailola *et al.* 1993). Spawning fish and larvae are encountered in waters with surface temperatures between 20-30°C. *T. maccoyii* is an opportunistic feeder, preying on a wide variety of fishes, crustaceans, cephalopods, *Sarpa salpa*, and other marine animals.
Importance	This species is very prized in Japan for the *sashimi* market and in New Zealand specialized fisheries for *sashimi*-quality has been developed. *T. maccoyii* is threatened by overfishing, was called to be declared an endangered species under the Endangered Species Act (1992) and listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

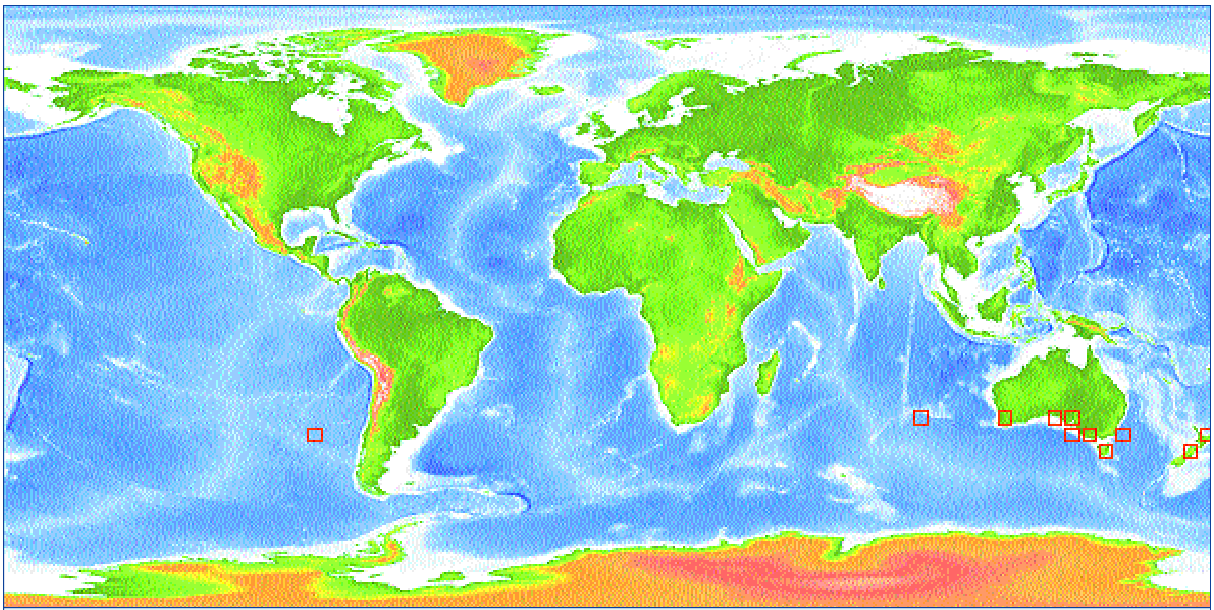


Figure 73. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Thunnus maccoyii* (FishBase 2002)

Fishery trends

Both southern and northern bluefin tunas are captured worldwide. Because of their flesh quality, bluefin tuna are among the most desired and expensive species; the Japanese market ("*sushi*"[1] and "*sashimi*"[2] tradition) is the main driving force for the fishery. Overfishing in many areas could adversely affect stock status. The northern bluefin tuna fisheries are therefore regulated by the International Convention for the Conservation of Atlantic Tunas (ICCAT), and the southern bluefin tuna by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT). As a consequence of overfishing, regulations and quotas are annually established or revised by these regional management bodies. The global catch of all bluefin tunas was higher in 2000 (65 426 tonnes) than in 1991 (45 499 tonnes) but was well below the peak in 1996 (Figure 74).

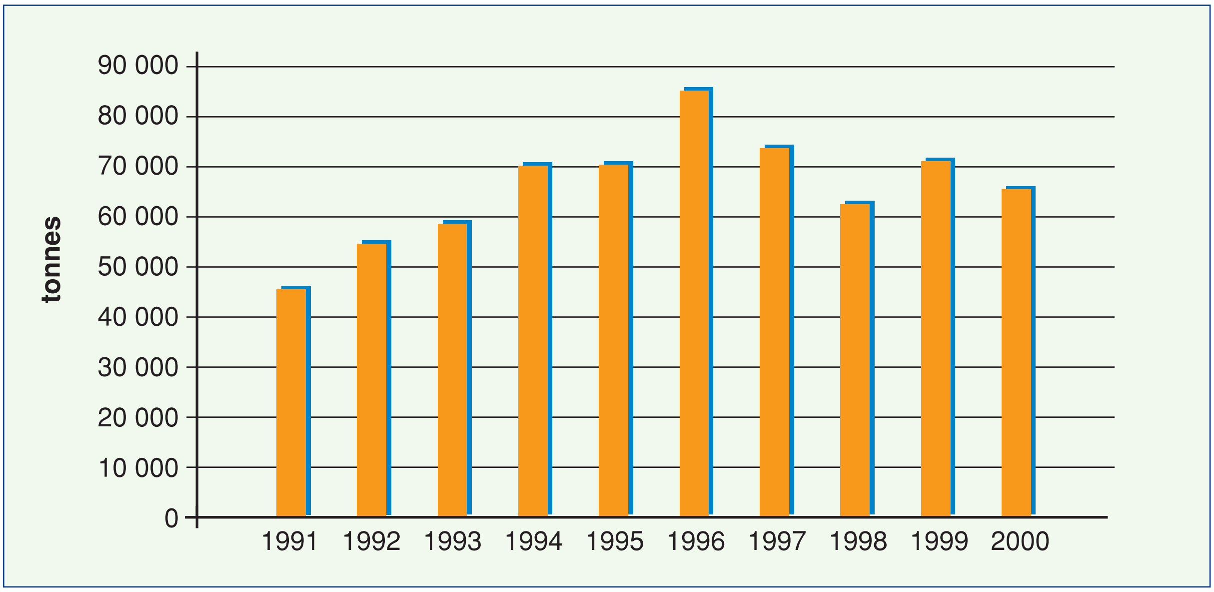


Figure 74. Global trends in the total bluefin tuna catch 1991-2000 (FAO 2002b)

Bluefin tuna fishing is mostly carried out using purse seines, longlines, traps, hand lines and harpoons (a traditional activity in the Straits of Messina, Italy), driftnets (now almost totally banned globally), etc. In 2000, the leading bluefin tuna fishery continent was Asia (25 762 tonnes), followed by Europe (20 288 tonnes), Africa (8 989 tonnes), Oceania (5 664 tonnes), North America (4 030 tonnes) and others (693 tonnes). The impact of intensive fishing is compounded by new fishing technologies, which make it possible to detect bluefin tuna shoals, e.g. helicopters and true-motion sonar systems; and a large proportion of the world's bluefin tuna are now caught by industrial fisheries. The Mediterranean and the Black Sea areas accounted for 37% of the total catch of bluefin tunas in 2000, followed by the Northwestern Pacific (17%) and the Eastern Indian Ocean (14%) (Figure 75). At that time, Japan was the leading tuna fishing country with a catch of 18 984 tonnes, followed by France and Spain (Figure 76).

Purse seine fisheries have become the most important provider of tunas for capture-based aquaculture. Due to the technological developments of fishing operations, purse seining is more efficient than longlining as it targets identified shoals. The pressure on bluefin tuna fisheries in the Mediterranean area has increased considerably over recent years. International organizations such as the Conference on the International Trade of Endangered Species (CITES) have warned

1 Japanese cold snack of cold rice, flavoured and garnished (in this case with tuna)

2 Japanese dish of garnished raw fish in thin slices

about a decline in the abundance of resources and the risk of their exhaustion. It is vital for future fisheries management to follow a precautionary approach, maintaining the status of these stocks in the absence of sufficient information, and to ensure that the existing equilibrium is not disrupted further (FAO/GFCM/CGPM 2003).

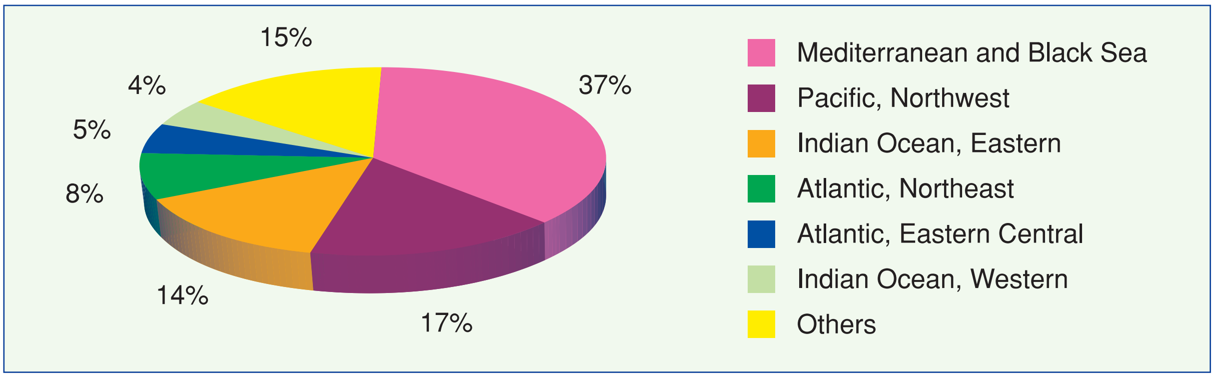


Figure 75. Total bluefin tuna catch by area in 2000 (FAO 2002b)

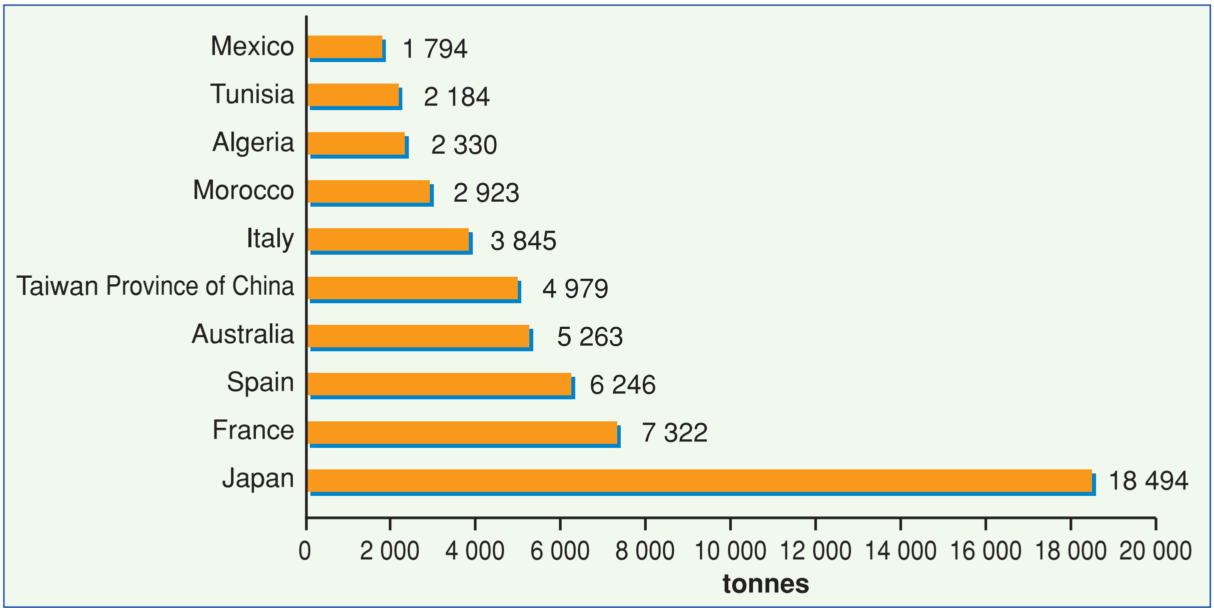


Figure 76. Capture fisheries for bluefin tuna: the top ten countries in 2000 (FAO 2002b)

Northern bluefin tuna

The catch of northern bluefin tunas (*Thunnus thynnus*) was greater in 2000 than in 1991 but peaked in 1996 (Figure 77).

Europe was the leading continent in 2000 (20 288 tonnes), followed by Asia (16 471 tonnes), Africa (8 987 tonnes) and North America (4 030 tonnes). Oceania ranked last with 21 tonnes.

The Mediterranean and the Black Sea are the major fishing areas, with 48% of the global catch in 2000 (Figure 78). The fishery was the first industrial fishery in the world using the traditional tuna trap, based in several places along the Mediterranean coastline. Economic support from Japanese interests to North African countries during the 1980s and 1990s, and joint ventures with European companies, have increased the fishery activities of Mediterranean countries and their commercial capacities (De la Serna *et al.* 2002). The Mediterranean is followed by the Pacific Northwest (22%) and the Northeastern Atlantic (11%) as the major capture areas (Figure 78).

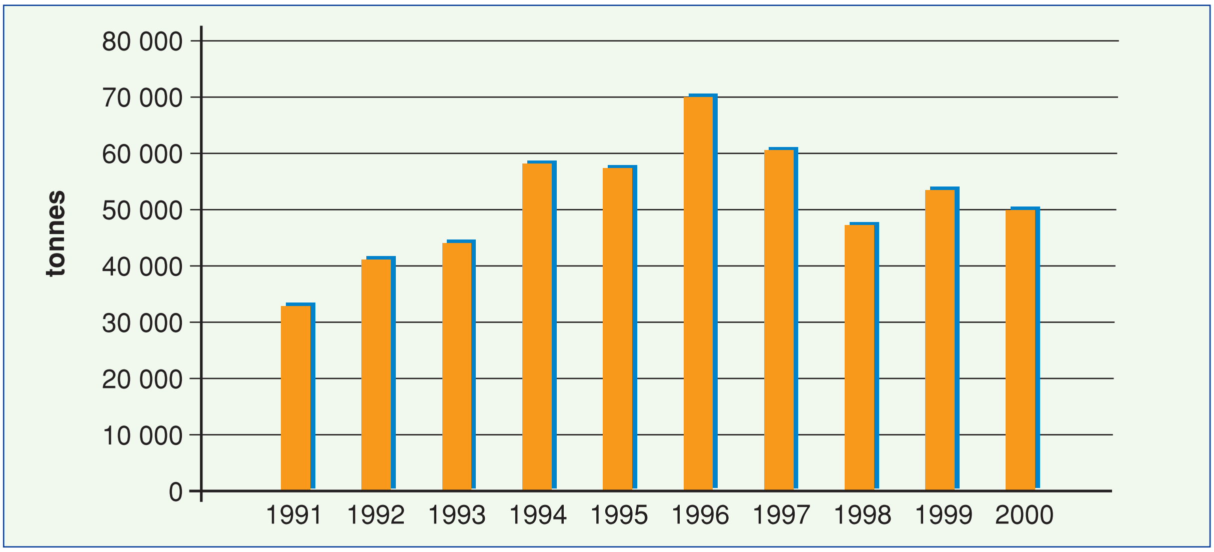


Figure 77. Global catch of northern bluefin tuna *(Thunnus thynnus)* 1991-2000 (FAO 2002b)

In 2000, Japan was the leading country with 12 163 tonnes (10 040 tonnes in Northwest Pacific, 890 tonnes in Mediterranean and Black sea, 553 tonnes in Northeast Atlantic, etc.), followed by France with 7 322 tonnes (Figure 79). In 2000, the catch of industrialized countries totalled over 30 000 tonnes, accounting for 67% of the total.

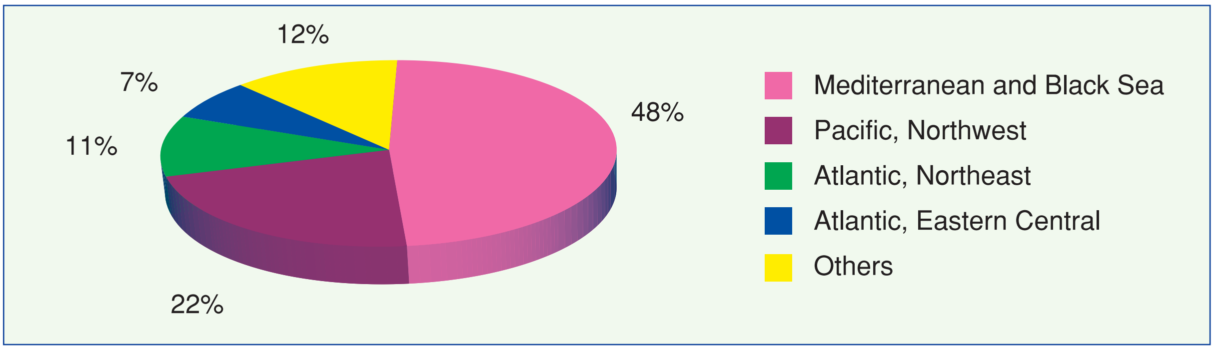


Figure 78. Global catch of northern bluefin tuna *(Thunnus thynnus)* by area in 2000 (FAO 2002b)

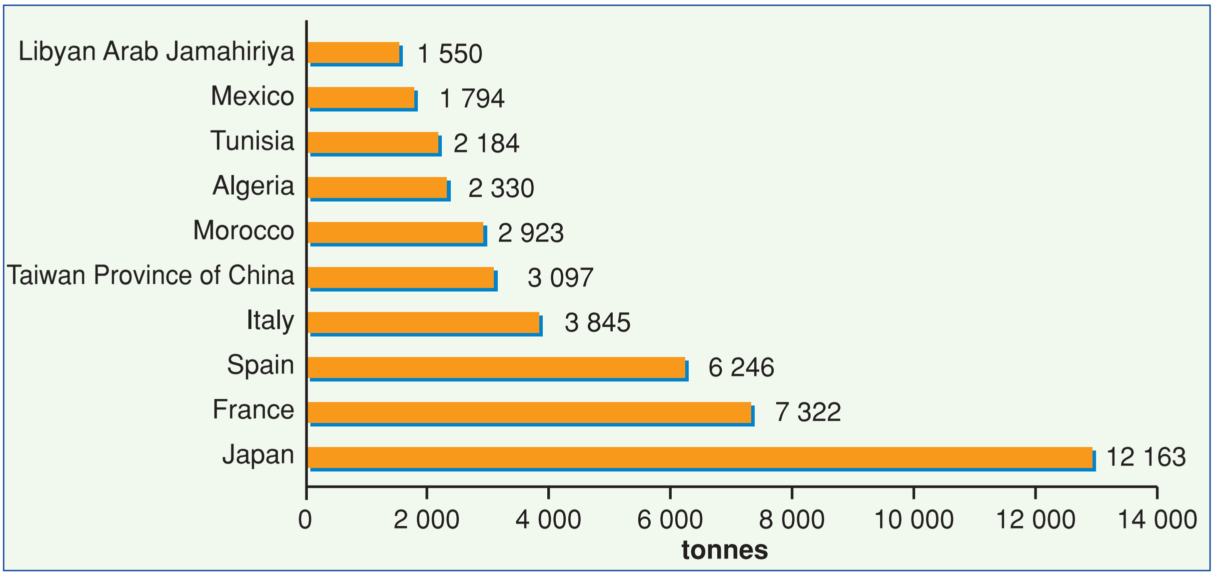


Figure 79. Capture fisheries for northern bluefin tuna *(Thunnus thynnus)*: the top ten countries in 2000 (FAO 2002b)

Southern bluefin tuna

Southern bluefin tuna (*Thunnus maccoyii*) data shows a cyclical trend (Figure 80); the extremes during the decade 1991-2000 were from just over 12 000 tonnes to nearly 18 000 tonnes.

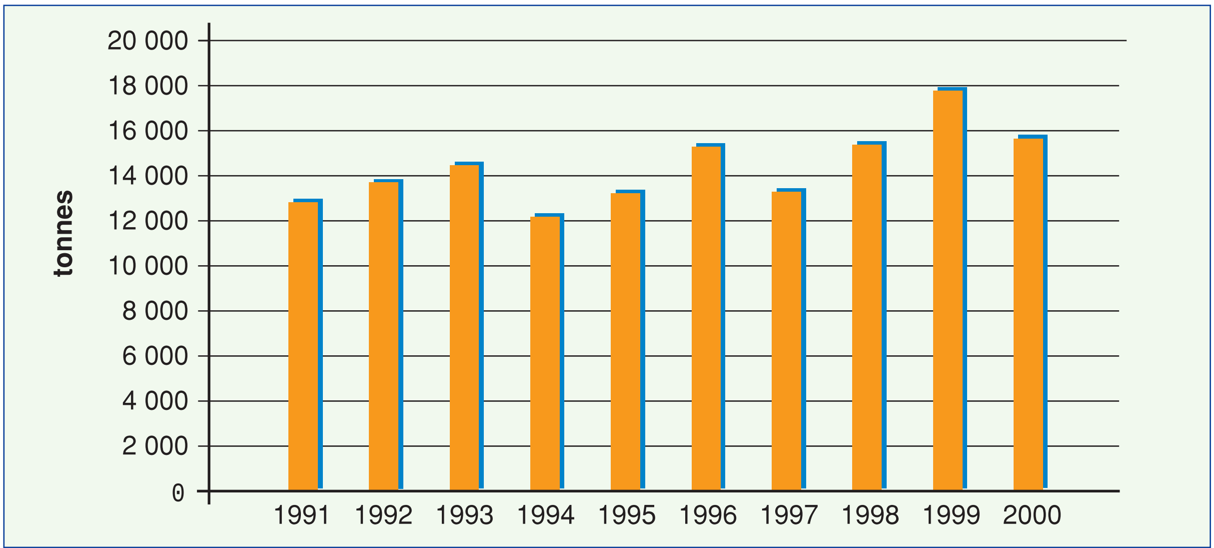


Figure 80. Global catch of southern bluefin tuna *(Thunnus maccoyii)* 1991-2000 (FAO 2002b)

In 2000, southern bluefin tuna (*Thunnus maccoyii*) was captured mainly in Asia (9 291 tonnes) and Oceania (5 643 tonnes). Total captures for 2000 amounted to 15 629 tonnes. The Eastern Indian Ocean area accounts for nearly 60% of the total with a catch of 9 317 tonnes (Figure 81). During the past two years (2001-2002), the main fishery area in Australia is around Port Lincoln (South Australia), with purse seine fleets as the main catching method.

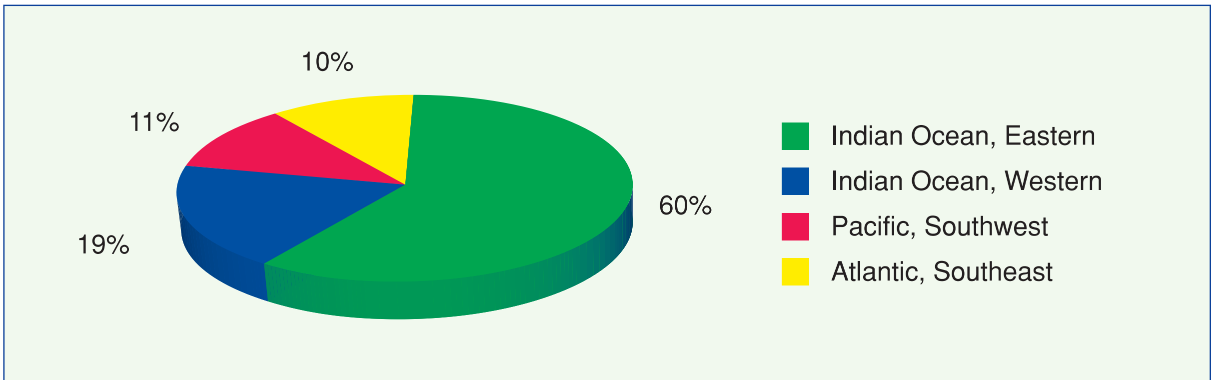


Figure 81. Global catch of southern bluefin tuna *(Thunnus maccoyii)* by area in 2000 (FAO 2002b)

In 2000, Japan was the leading fishing country with 6 331 tonnes, followed by Australia with 5 263 tonnes (Figure 82). In that year, most southern bluefin tuna (76%) was caught by the fishing fleets of industrialized countries. 12% was caught by Taiwan, Province of China.

The capture-based aquaculture of southern bluefin tuna began as a result of the declining Australian fishery for this species. The Australian catch peaked in 1982 at 21 500 tonnes (Fishstat Plus 2002) but, owing to increasing concerns about the sustainability of the fishery, a TAC (total allowable catch) system was implemented by the CCSBT to limit and manage the catch. Steadily reducing TACs (14 500 tonnes in 1984, 6 250 in 1998 and 5 265 tonnes since 1990) provided the necessary incentive for southern bluefin tuna fishing operations to investigate the potential for capture-based aquaculture (Clarke 2002). Today, Australian bluefin tuna is mainly sold to Japan; in 2001, 99% of the Australian bluefin tuna farmed in Port Lincoln (South Australia) was exported to the Tsukiji market, Tokyo.

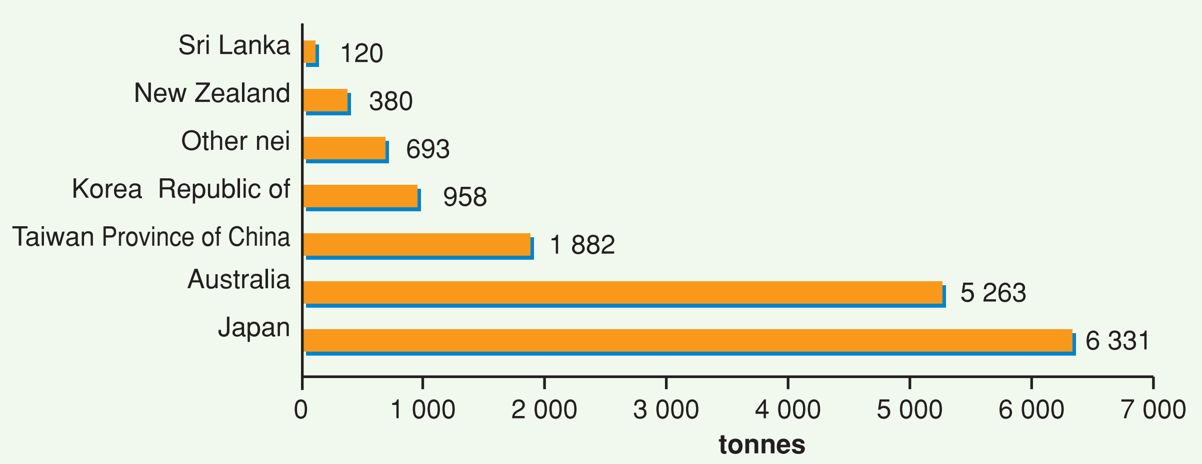


Figure 82. Catch of southern bluefin tuna *(Thunnus maccoyii)* by country in 2000 (FAO 2002b)

Japan is the main market for the bluefin tuna caught in the global fisheries: the Japanese custom to eat fresh tuna as "*sushi*" and "*sashimi*" is the driving force behind the development of tuna fishing, and is also supporting the development of the capture-based aquaculture sector, worldwide.

Availability of "seed" for capture-based aquaculture

Bluefin tuna shoal by size, sometimes together with other species (e.g. yellowfin, albacore or skipjack). Natural stocks are known to fluctuate considerably year-by-year, and these fluctuations are attributed to either food availability and/or predation at some period of their early life history – the so-called "critical period" (Cushing 1974, 1990). "Shoalfishes" normally adopt ecologically antipredatory behaviour (Masuda and Tsukamoto 1999). This mechanism is of vital interest to fishermen, because it largely determines the success or failure of fishing techniques and tactics and, due to this behaviour, bluefin tuna schools have been heavily exploited. Tuna prey on other schooling fish e.g. anchovies, and the effect of their capturing activities are visible on the sea surface. This predatory behaviour allows fishermen to easily detect bluefin tuna schools.

As bluefin tuna are widely distributed and migrate for thousands of kilometres, a general understanding of tuna movement and migrations is necessary for a more accurate analysis of bluefin tuna size availability for capture-based aquaculture. In the northeastern Pacific *Thunnus thynnus* tend to migrate northward along the coast of Baja California and California, from June to September. Off the Pacific coast of Japan, they migrate northward in summer and southward during winter. Adults may enter the Sea of Japan from the south in early summer and move as far north as the Okhotsk Sea; most leave the Sea of Japan through the Tsugara Strait, north of Honshu (www.fao.org/fi/sidp/species/th_th_ht.htm).

There are only two confirmed spawning locations: the Gulf of Mexico in the Western Atlantic and the Mediterranean Sea in the Eastern Atlantic. Spawning in the Gulf of Mexico occurs between mid-April and mid-June when females (typically 8 years old) each release approximately 30 million eggs. According to Buck (1995), sexual maturity is reached at the age of 5 to 8 years, depending on the stock. Some fishery biologists believe that eastern Atlantic bluefin tuna reach sexual maturity several years earlier than those in the western Atlantic (possibly as young as ages 4 or 5), a claim disputed by some other biologists. All the bluefin tuna collected during the spawning season in the Balearic Islands in 2001 were between 19 and 34 kg and had fully matured (spawning) ovaries – a fact that would apparently confirm that the eastern stock of Atlantic bluefin tuna are able to spawn from 3 years old (Abascal, Megina and Medina 2003). Further studies of bluefin tuna biology are clearly necessary. In 2002, a captive-raised bluefin tuna (145.6 cm total length, 35.2 kg body mass) was found to be a hermaphrodite, the first record of hermaphroditism in this species (Sawada *et al.* 2002). The highest density of bluefin larvae, the primary indicator of spawning, occurs in the northern Gulf of Mexico, with lesser larval concentrations appearing off the Texas coast and in the Straits of Florida (NRC 1994).

In the Eastern Atlantic, spawning occurs exclusively in the Mediterranean: usually from May to July in the Balearic Sea, the South Tyrrhenian Sea, and in the southern Mediterranean. Aggregations of juveniles have been reported in the eastern Aegean sea, in the Southern Adriatic Sea, in the Tyrrhenian Sea, in the Ligurian Sea and in the Balearic area, sometimes close to the coast (De la Serna *et al.* 2003). The larval abundance of tuna around the Balearic Islands was determined between June 15 and July 10, 2001, as part of a Spanish research project. The highest abundance was observed south of Minorca and along the midsection of the Mallorca channel (García-Gómez *et al.* 2003).

Bluefin in the South Atlantic belong to a distinct southern population, the southern bluefin tuna (Figure 83), with known spawning areas south of Java, Indonesia. The aggregations of southern bluefin tuna juveniles swim near the surface during their migration between the spawning areas and western Australia, where individuals of class O are concentrated to the dispersion areas, close to Tasmania and New Zealand.

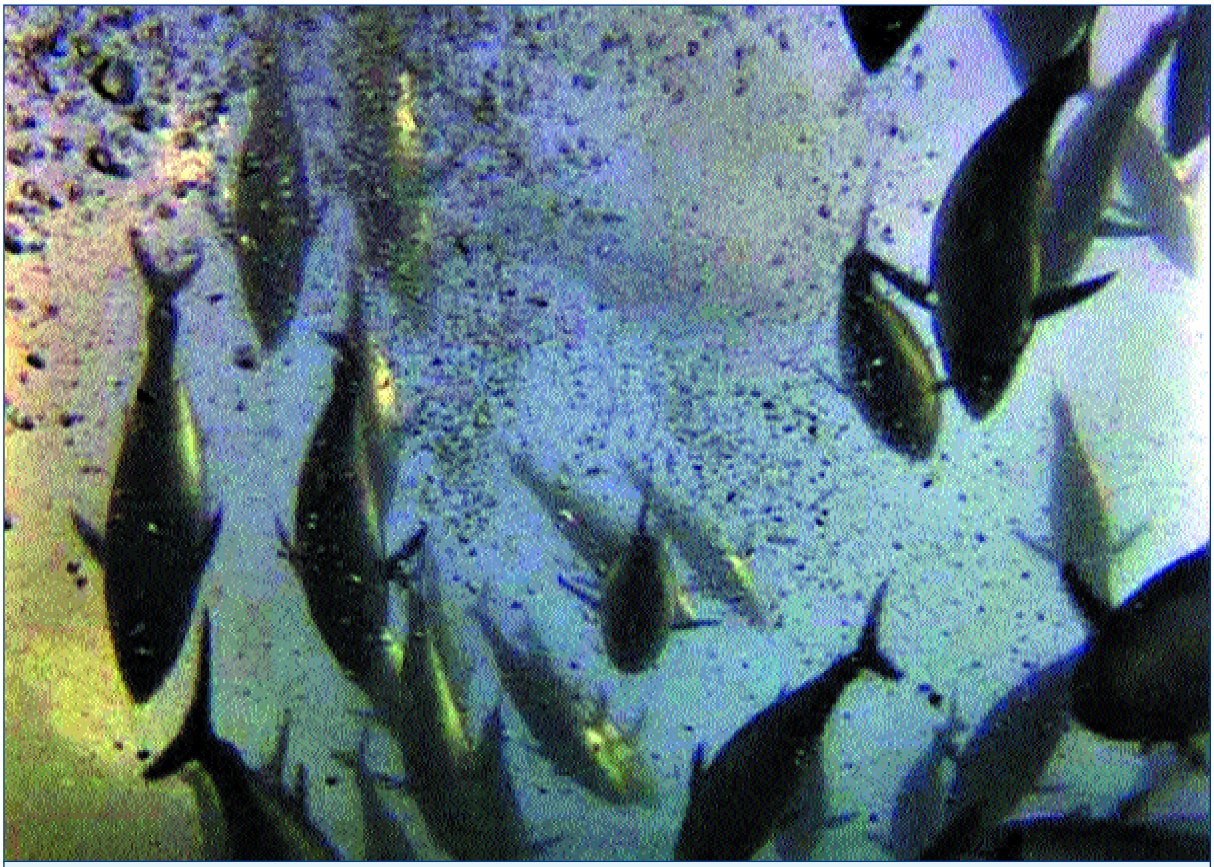


Figure 83. Southern bluefin tuna *(Thunnus maccoyii)* (Photo: L. Mittiga)

Large size, slow growth, late age-at-maturity, short spawning duration and long life spans are characteristic of temperate seas bluefin tuna. The turnover of these species is slow and has characteristics similar to those of the "k-selected" species (Odum 1998). Atlantic bluefin tuna and southern bluefin tuna live in temperate to cold waters but only reproduce in warm waters. Reproduction could be the key ecological factor for the fish from temperate and cold seas, because of the higher risk of starvation for larvae and young juveniles. It could be argued that tunas have partially resolved this difficulty, by means of yearly reproductive migrations into warmer and more stable environments. However, spawning duration and frequency are much shorter for temperate than tropical sea tunas (Fromentin and Fonteneau 2001).

The Mediterranean fishery for bluefin tunas is based on migration patterns. At the beginning of the season, from May to July, those that arrive in the Mediterranean Sea are in the "genetic phase" (large pre-spawned fish); at the end of the season, from mid July to September, they are on their way out of the Mediterranean, moving into the Atlantic Ocean for feeding (the "trophic phase" or large post-spawned fish) (Doumenge 1999). The first commercial tuna capture-based farm, established in Ceuta (Spain), was based on the capture of large post-spawned tuna (mostly over 150 kg). In these locations, catches have shown that the average weight of bluefin tuna leaving the Mediterranean is in the range 185-215 cm TL (from 106 to 150 kg), which is 18% less than the specimens of the same class entering the Mediterranean. This is the effect of post-spawning weight loss.

Since 1997, most of the tunas caught for capture-based aquaculture are moved from the catching area, inside cages, to the on-growing cages. In Croatia, the capture of juveniles for capture-based aquaculture occurs at the end of the spring and in early summer. The individuals captured range from extremely small fish (less than 10 kg, sometimes undersized or just within the legal minimum landing size set by ICCAT of 6.4 kg) to somewhat larger fish (20-80 kg). They are caught by Italian and Croatian purse seiners in the Adriatic Sea (Miyake *et al.* 2003; Tudela 2002b). Spanish, French and Italian seiners supply most of the fish for the farms in Murcia (Spain). These fish are caught in the Western Mediterranean, particularly near the Balearic Islands; they range from small (20-80 kg) to medium size (80-120 kg) and are mostly immature, but also include some matured fish of larger sizes (Miyake *et al.* 2003). Bluefin tuna for the Maltese farms are mainly caught in international waters, the main fishing period being from May to July. The fish size ranged from 80-250 kg in 2000, and from 50 kg to 620 kg in 2001 (Miyake *et al.* 2003).

Fishing for northern bluefin tuna (*Thunnus thynnus orientalis* subspecies) in Mexico for capture-based aquaculture is more difficult than in any other part of the world, due to problems with the depth at which the fish are able to swim there. The main fishing period is from July to late August, but depending on fishing locations, the season can extend into November. The catches occur mainly at night and rely on the presence of bioluminescence to locate bluefin tuna schools. Individuals range from 15-45 kg, with smaller fish being caught in southern areas and larger ones in northern regions (Sylvia, Belle and Smart 2003).

In contrast to the practice in other regions, juveniles of 150-500 g body weight are caught off the coastal areas of Japan during spring and summer (Ikeda 2003). Fishing activities in Australia have centred in South Australia, mostly established in Port Lincoln, which is situated in the South Australia Gulf. The fishing fleet consists of purse seiners, and a "rod fishing" flotilla. Specimens have a range from 20-25 kg, although some schools of 50 kg specimens are sometimes encountered. The fishing season lasts from December to May.

Catching methods for "seed" material

Specimens that are to be used in capture-based aquaculture are caught with traditional fishing gears. The selection of fishing gear is very important: it must take into account the stress that occurs during fishing and should provide specimens that able to adapt easily and rapidly to captivity, which have not suffered physiological stress that could have survival implications. Tuna are prone to a build up of lactic acid, which is produced during muscular contractions following capture. Due to their complex circulatory system, it is essential that no external stress causes damage to the "*rete mirabilis*"; any damage or lesions are liable to cause long-term dysfunctions which may lead to the death of the individual.

Individual "rod fishing", with a single fish hook, has been adapted for catching juvenile and sub-adult specimens. Barbless hooks can be used for capturing specimens weighing several kilos. However, the fishing technique most physiologically suited to catching bluefin tuna for capture-based aquaculture is the purse seine (Doumenge 1999). The purse-seine fishery has become the most important provider of live tunas (minor quantities are provided by tuna traps) for capture-based aquaculture. The fish are first caught using a purse seine in the traditional manner, before being transferred to transport cages by "swimming through" (Di Natale *et al*. 2003), as described in the following section of this report. Purse-seining is a modern fishing technique developed in the 1960s. It involves paying out a large net off the stern of a fishing vessel, with a bottom weighted (lead) line and a top float line that extends the net vertically in the water. A second smaller vessel (skiff) pulls one end of the net from the purse seiner as both vessels encircle the school of fish from opposite directions until finally reconnecting the skiff end of the net with the purse seine vessel (Figure 84).

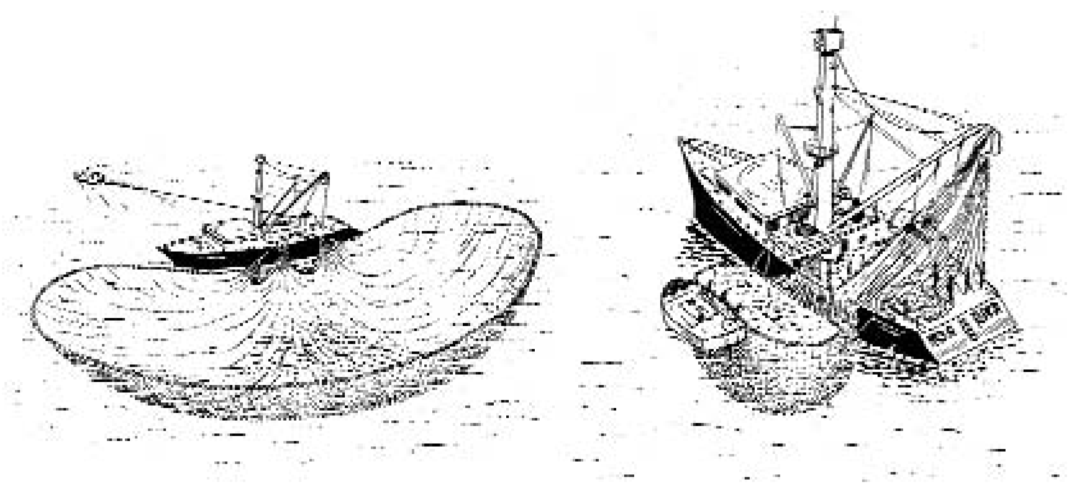


Figure 84. Purse seine system (Source: FAO)

The purse seiner then draws the bottom lead line closed, creating a "purse" to entrap the school of tuna (Buck 1995). Purse seining is a very efficient system that can be defined as an "industrial fisheries tool", is species-selective, and in the Mediterranean Sea does not entail high bycatches of cetaceans (Tudela 2002b). It is the only system that allows the transfer of live fish to the capture-based aquaculture cages. It is therefore an essential component for industrial tuna farming, and is used all over the world. Table 44 shows purse seine captures versus the total catch in the Mediterranean area (Tudela 2002b).

Table 44. Catch of bluefin tunas by purse seine compared to total catch in the Mediterranean

Catch (tonnes)	1998	1999
Purse seine	20 391	14 061
Total	26 813	24 036

While purse seine catches are showing a decrease, mostly due to the ICCAT catch limits, the total amount of farmed bluefin has continuously increased and the proportion of farmed tuna in the total purse seine catches has also increased annually. 30% and 37% of purse seine catches in 1999 and 2000 respectively were introduced to capture-based aquaculture (Miyake *et al*. 2003). Purse seining in the Mediterranean is illustrated in Figure 85, while Figure 86 illustrates the general operation of the purse seining system.

Figure 85. Purse seine operation in the Mediterranean

Another technique employed in bluefin tuna fishing is the use of tuna traps placed in the course of the trophic or genetic migration. As in purse seining, it is essential not to stress the animals. A floating cage is attached to the end chamber of the tuna trap. This system is particularly suited to the capture of specimens belonging to the “giant” class, weighing hundreds of kilos (Doumenge 1999). In Japan, bluefin tuna fingerlings are caught by mid-water trawls. The mortality rate at the time of stocking was 85% in 1974; however, after some modifications to the fishing gear, mortality declined to 15% in 1984. These tuna weigh 100-300g at the time of stocking (Norita 2003).

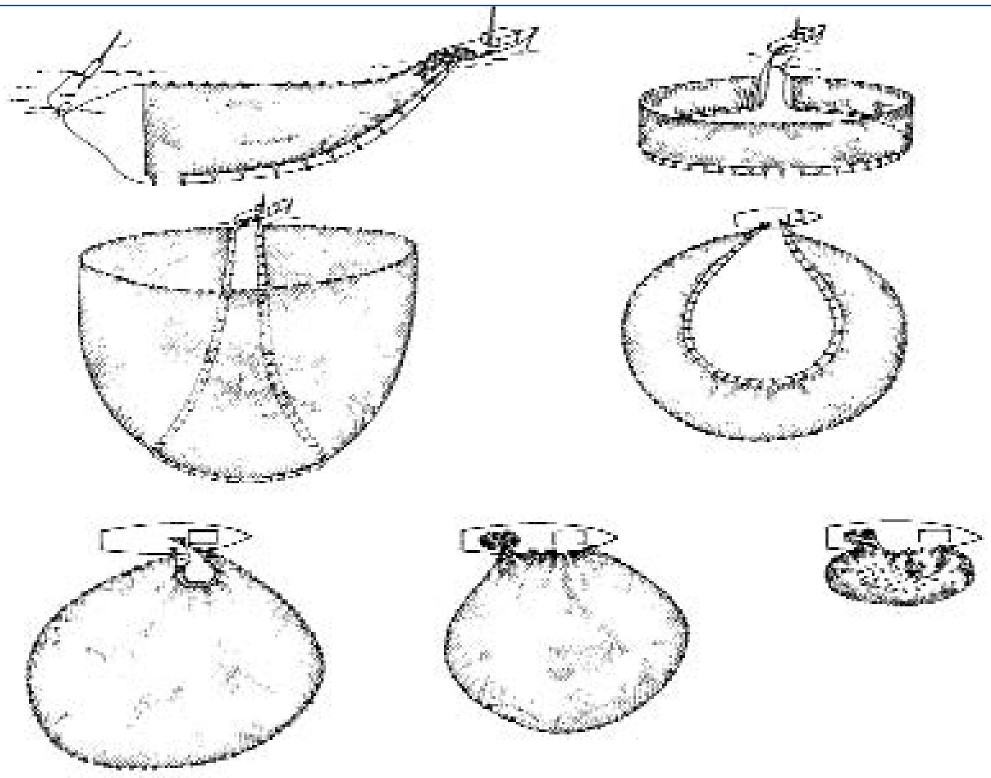


Figure 86. Operation of the purse seine system (Source: FAO)

Mortality rates from catching to stocking

As noted earlier, farmed bluefin tuna are mostly provided by purse seiners. The transfer of live fish from the seine to the towing cages is done in the open sea by swimming the fish from the purse seine into the towing cage (e.g. 90 m in circumference), generally where the catch has occurred. The transfer of the live fish captured with the purse seine system to the towing cages is affected by joining both nets, either by a "zipper system" or "sewing" them together. The tuna are then gently forced into the towing cage by lifting the purse seine. Several purse seine catches can be added to one towing cage before it is eventually towed to the grow-out area. Transfers from the catching area to the on-growing site can take from a few days to several weeks, depending on the position of the fishing area. In Mexico, towing distances can range from 90 to more than 800 km.

The transportation of adult specimens weighing hundreds of kilos to farming or fattening cages requires vessels capable of towing floating cages of great size at speeds not exceeding 1-1.5 knots, to avoid high bluefin tuna mortality rates due to the build up of lactic acid. Care must be taken not to crowd the fish, but rather to create a tunnel into which they can swim without any manipulation. These are manoeuvres difficult to execute, but the result is schools formed by specimens in perfect condition, which adapt rapidly to captivity. The low speed necessary for transport implies long return voyages that may take weeks, and it is also necessary to feed the fish en-route. This transport is usually done by very powerful tugboats that may cost in excess of US$ 2 500/day (Agius 2002). In Croatia fish are transhipped from purse seine fishing grounds to the farms by using a smaller cage (smaller specimens) towed by a boat - a distance up to several hundred miles if fish are captured within the Adriatic Sea or in other areas of the Mediterranean (Miyake *et al.* 2003). The counting of the fish trapped within the seine is usually done by divers, while cameras are used to count the fish when they pass from the seine to the towing cage. Average weight is preliminarily estimated from the dead fish in the seine.

In Australia, southern bluefin tuna schools are seined and transferred through a connection between nets to specialised Bridgestone cages/pontoons. As much as 100-130 tonnes of 15-25 kg southern bluefin tuna per pontoon are towed back at about 1.5 knots to the farm areas adjacent to Port Lincoln (South Australia), a process that may take several weeks and involves some feeding of the tunas. Mortality rates have averaged 4%, but in 2002 they decreased to ~2% (B. Jeffriess, pers. comm. 2002).

Mortality rates in the grow-out cages in Croatia were observed to be particularly high during the first month of adaptation (2.1%), decreasing significantly during the next months (0.6%). Stress related mortality in conjunction with injuries during seining and transporting procedures may cause high mortality rates. Compared to more advanced stages, smaller juveniles seem to be more stress sensitive (Katavic, Vicina and Franicevic 2003a,b).

In Japan, juveniles are caught in early spring by trolling in coastal waters. The newly-caught young fish react strongly to the stress of capture and confinement. The jaws or other parts of the bodies of these fish are sometimes injured (Munday *et al.* 2003). The skin is also delicate, and is damaged easily by mishandling, leading to high mortality rates at first (Nash 1995).

Trends in aquaculture production

According to Ikeda (2003) the global supply of cultured tuna reached 20 000 tonnes in 2001. Bluefin tuna are cultured world-wide (Figure 87). Northern bluefin tuna are reared in the Mediterranean area (Croatia, Spain, Italy, Turkey, Morocco, Tunisia, Malta) and in Canada, Mexico, Japan and the USA; southern bluefin tuna are reared in Australia. Some of these activities are irregular or are at experimental levels. In general, tuna farming is expanding and license requests are increasing (France, Italy, Malta, etc.) and new countries are coming onto the scene, such as Greece and Libya (Agius 2002).

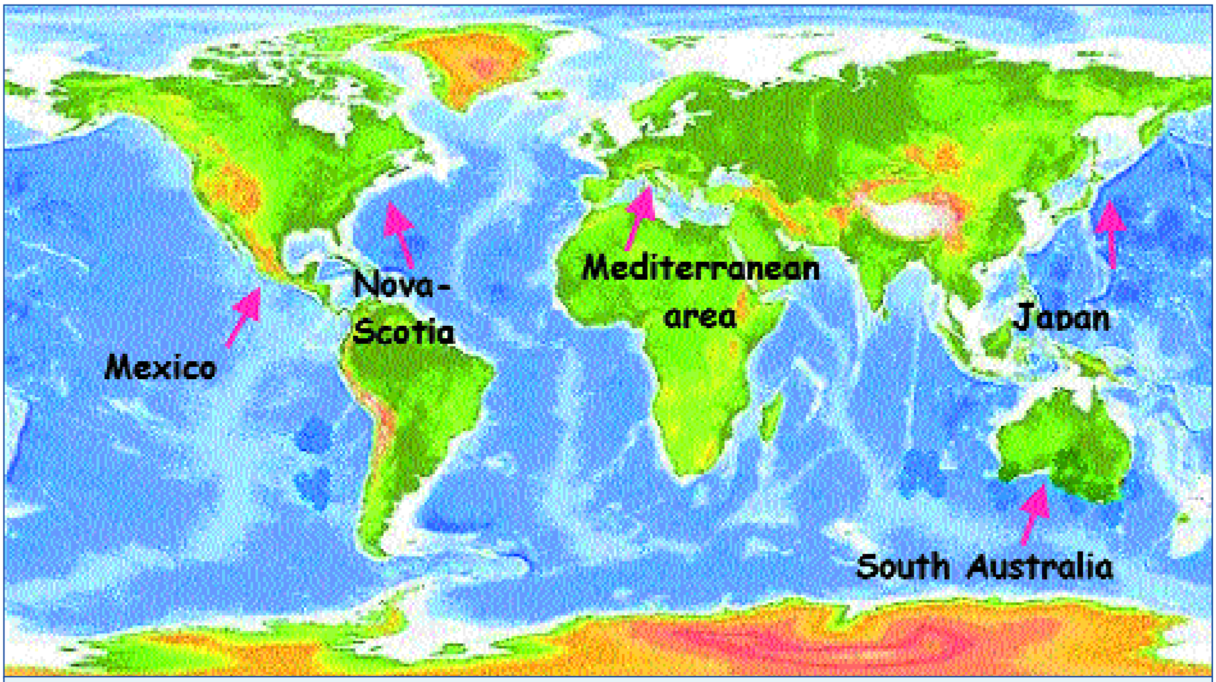


Figure 87. Location of tuna capture-based aquaculture

The supply of capture-based farmed tuna is mainly destined for Japanese "*sashimi*" but constitutes only 4% of the total amount of tuna required by the Japanese market. The supply of tuna (all the species) to the Japanese market ranged from 451 000 to 507 000 tonnes during the four years 1998-2001, but the ratio of fish with a high product value ("*toro*") is decreasing (Ikeda 2003). "*Toro*" form only approximately 30% of the fishery catches but the capture-based farmed tuna are almost entirely considered as "*toro*". "*Toro*" and other products are described in the marketing section of this chapter. The advantages of cultured tuna are its low price (a third or a half the price of captured tuna) and its easy availability in supermarkets, fresh fish shops or "*kaiten-zushi*" restaurants throughout the year (Ikeda 2003).

The trend in bluefin tuna capture-based aquaculture production from 1999 to 2001 is shown in Figure 88. The main capture-based aquaculture producers of tuna in 2001 were Australia, Spain, Croatia, Malta and Mexico (Figure 89). In these countries farms are often in joint venture with Japanese companies.

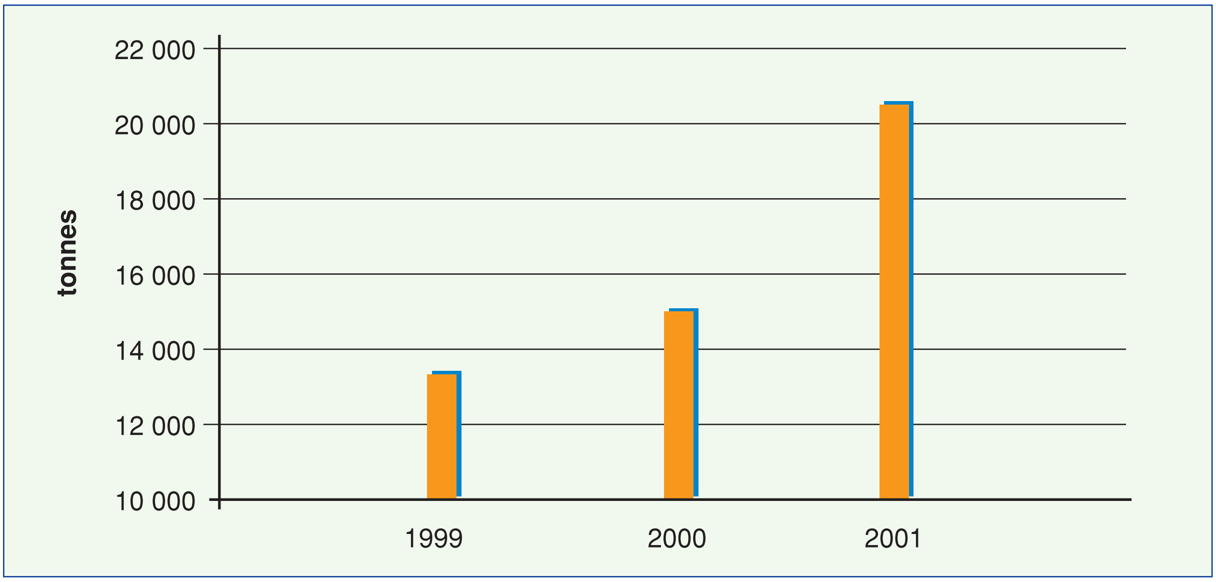


Figure 88. Global production of capture-based farmed bluefin tuna 1999-2001

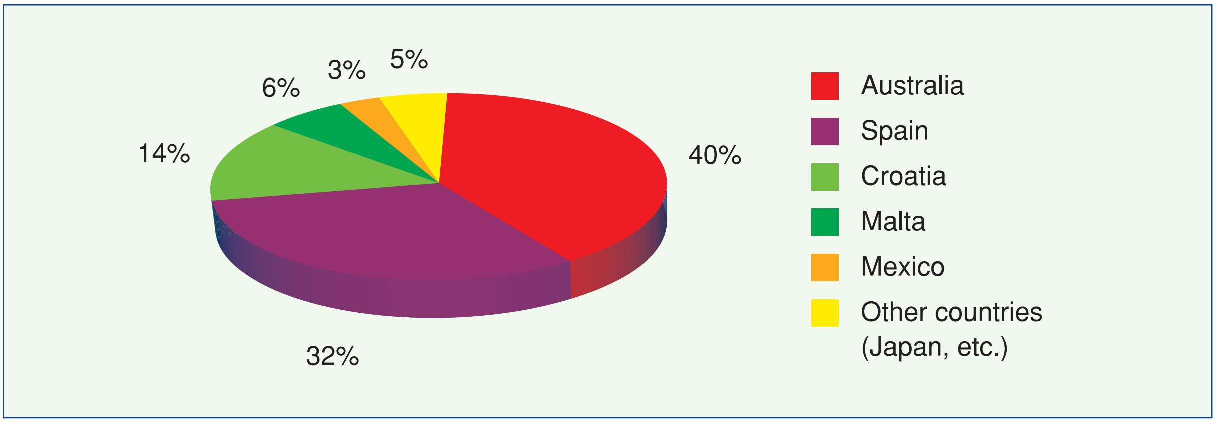


Figure 89. Production of bluefin tuna by capture-based aquaculture by country in 2001

Capture-based tuna aquaculture in Japan

Motoo Inoué, a Tokai University Professor financed by the Fisheries Agency of the Japanese Agriculture Ministry, started experimentation on bluefin tuna culture in 1970 (Inqué 1973a,b). The aim was to grow out juveniles to commercial size and, in the future, to actually breed the bluefin tuna. The ethology and physiology of the species created several problems in adapting the species to captivity, resulting in low survival rates due to the stress during capture. The results of three years of experiments were quite poor from a practical point of view (Ueyanagi *et al.* 1973; Le Gall 1974, 1977; Harada 1979), but the way was opened for the capture-based aquaculture of bluefin tuna. Eight companies and organizations currently farm bluefin tuna in various locations in Japan: 3 in Okinawa, 4 in Nagasaki, 2 in Wakayama, 6 in Amami and 3 in Ehime and Kochi (Ikeda 2003).

In contrast with tuna culture methods elsewhere, juveniles of 150-500 g body weight are caught off the coastal areas of Japan and are reared for 3 to 4 years in net cages until their body weight increases to between 30 and 70 kg, when they are harvested. The trend in Japanese bluefin tuna capture-based aquaculture production from 1998 to 2001 is shown in Figure 90.

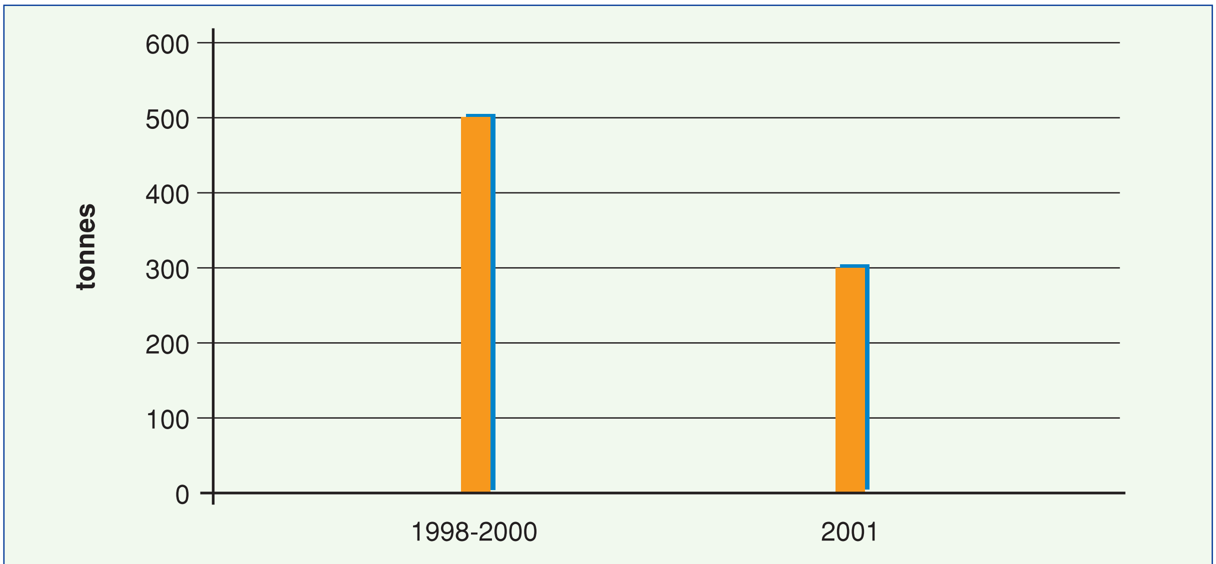


Figure 90. Production of capture-based tuna aquaculture in Japan (Ikeda 2003)

The most severe problem for Japanese bluefin tuna capture-based aquaculture is supplying fingerlings to culture farms. Even after capture, the newly-caught young fish react strongly to the stress of their capture and confinement. Their skin is also delicate, and it is damaged easily by mishandling. As a result, mortality rates are high at first. Fish which survive and acclimatise to farm conditions remain susceptible to mortality from sudden changes of climatic conditions, e.g. a fall in water salinity due to typhoon and monsoon rains, or a drop in the oxygen level (Nash 1995).

It is also necessary to improve the rearing techniques used during growing out. The loss of juvenile and young adult bluefin tuna is often caused by collisions with the walls of tanks or nets, which fatally damage the bones of the vertebral column and the parasphenoid (Miyashita *et al.* 2000). The high number of deaths caused by bumping into the tank and net-pen walls at dawn can possibly be attributed to visually disoriented fish. One experiment found that there is an incompatibility of the retinal adaptation with the change in the ambient light intensity, a problem that could cause the visual disorientation of the fish (Masuma *et al.* 2001). It is therefore possible that these visually disoriented juveniles are not able to control their high power swimming properly (Masuma *et al.* 2001). As capture-based fingerlings are difficult to obtain and the supply is uneven, the industry must seek to rely on hatchery-produced fingerlings. A new and important goal was finally reached in June 2002 (Box 1).

Box 1. A mark of the future: rearing tuna in a hatchery

JAPAN RESEARCHERS BREED BLUEFIN TUNA FULL CYCLE FOR THE FIRST TIME

For the first time, in June 2002, researchers at the Kinki University in Wakayama Prefecture successfully completed the full life-cycle of bluefin tuna. While Kinki scientists mastered the breeding of bluefin tuna as early as 1979, the fish have not been able to survive past an early age until this year. On June 23, an artificially reared adult bluefin tuna produced eggs for the first time (www.intrafish.com). The fish spawned one million eggs and the achievement may pave the way for full-scale farming of the species in the future.

The Japanese government has promoted a "tuna liberation project" in the past. Since 1993, the Fisheries Agency in Japan has spent ¥1.2 billion in establishing the bluefin tuna fish rearing and spawning in a facility - Amami Oshima. After this incredible achievement of completing the full life-cycle of tuna, it will be possible to increase the stock by reintroducing fingerlings in the wild.

Capture-based tuna aquaculture in the Mediterranean

In recent years, bluefin tuna culture has spread throughout the Mediterranean. This expansion is directly related to the interest and development of the Japanese market. The culture is specifically aimed at producing tuna that have the optimal fat content demanded by the "*sushi*" and "*sashimi*" market, and both fresh and frozen tuna farmed products are exported to Japan. In Japan, one kilogram of bluefin tuna can be sold for as much as US$ 430. About two thirds of the Mediterranean bluefin tuna that are exported to Japan are from capture-based aquaculture.

Tuna farming in the Mediterranean is expanding and the production accounts for more than half of the global total. The first commercial tuna farming operation in the Mediterranean area started in 1979 in Ceuta (Spain). Large, post-spawned lean tuna were captured in traps on their way out of the Mediterranean, put in large pens and fattened. As the fish were obtained from traps, the quantities raised every year were limited to a maximum of 200 tonnes (Miyake *et al.* 2003). Now, tuna are reared in several locations in the Mediterranean (Figure 91). The main producers are Spain (Murcia region), Malta, and Croatia, which together accounted for more than 11 000 tonnes in 2001. The Murcia region (Spain) alone exported more than 7 000 tonnes to Japan, worth more than € 150 million. The trend in the main Mediterranean tuna capture-based aquaculture producing countries for 2000 and 2001 is shown in Figure 92.

Mediterranean tuna farming is based on catches taken from wild populations (of different sizes), which are moved alive to floating cages in offshore areas. The fish are then kept in large cages for variable periods, ranging from a few months to years, depending on the farming location and fish size. In Malta, fish are put in the cages from May-July and kept there until October-January. The fish ranged from 80 to 250 kg in 2000 and from 50 to 620 kg in 2001. Two farms existed in Malta in 2001, when about 1 200 tonnes was exported. Three more companies were expected to start tuna farming around the Maltese Islands by 2003 and export figures were expected to reach 2 500 tonnes/year (Peric 2003b).

Figure 91. Location of capture-based tuna aquaculture in the Mediterranean

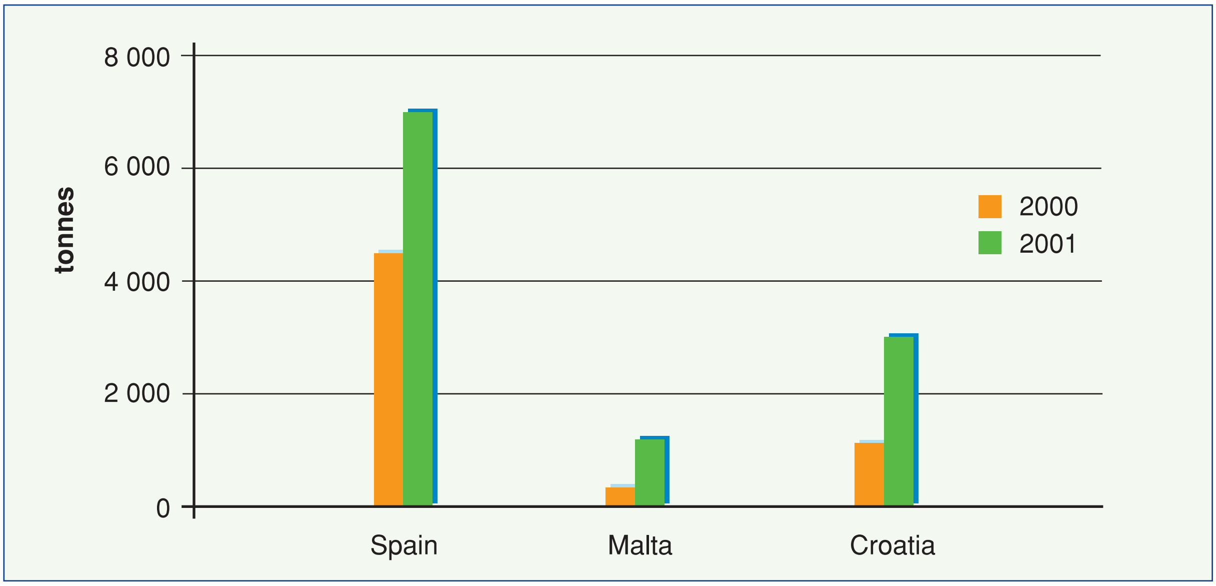


Figure 92. Capture-based aquaculture production of the main Mediterranean producers (2000-2001)

The capture-based aquaculture of tuna in Spain began in 1996 in the Province of Murcia. Tuna farmers are grouped within the Spanish bluefin tuna farmers association (ASETUN). The fish supply comes from purse seiners in the western Mediterranean, particularly around the Balearic Islands. The fish range from small (20-90 kg) to medium size (80-120 kg), and are mostly pre-maturity. Up to now, no fish are kept more than 10 months in this location (Miyake *et al*. 2003). Project proposals for new tuna farms have been submitted to virtually all autonomous government regions along the Spanish Mediterranean coast, from Andalucia to the Balearic Islands, including Catalunya (Tudela 2002b).

During the five years 1997-2001 bluefin tuna farming in Croatia averaged about 2 500 tonnes of harvested fish per year. The industry consists of six commercial companies using nine lease sites (Katavic *et al*. 2003a). Here, the capture of juveniles occurs at the end of spring to early summer. The individuals captured range from some extremely small fish (less than 10 kg, including undersized or just legal minimum size set by ICCAT at 6.4 kg) to small fish (20-80 kg), These are caught by the Italian and Croatian purse seiners in the Adriatic Sea. The farming period differs widely between farms, but usually lasts 2-6 months, while the smallest specimens are usually kept in cages to grow on for two or three years. Small tunas usually dominate the catch composition in the Adriatic Sea (Katavic, Vicina and Franicevic 2003a).

Experiments were carried out in Italy from 1978 to 1982, when some large bluefin tuna were cultured using a small floating cage in the Scopello trap (Sicily). However, commercial capture-based aquaculture of tuna did not start until between 1999 and 2000 in the south-west of Sicily, and in 2001 in the Central Adriatic Sea (Miyake *et al*. 2003). 100 medium sized tuna were farmed in Sicily in 1999; in 2001, 500 small tunas were farmed in the central Adriatic sea, four miles off Ortona. These two farms were built for experimental use. In 2001, a commercial farm was built near Trapani on the Tyrrhenian coast, and 400 tonnes of medium to large tunas were farmed (Miyake *et al*. 2003). Tuna farming in Italy is expanding, but it is meeting strong opposition from environmentalists.

In Morocco, experimental culture of bluefin tuna started in the mid 1990s. The Moroccan Kingdom and the Japanese Government undertook a joint venture: a large scale experimental project in the North-East of Morocco, on its Mediterranean Coast. Its main purpose was to develop the technology for artificial breeding. Two groups of bluefin tuna broodstock were kept in floating net cages moored in the open sea. The first group was composed of 75 giant bluefin tuna with a mean body weight of about 250 kg that increased to an average of 400 kg after three years of rearing. The second group was composed of 106 young bluefin tuna, which had an average of 55 kg mean body weight, which attained 350 kg after four years of rearing (Nhhala 2002).

One tuna farm in Turkey is situated off the southern coast and uses a cage 150 m in circumference. With a net depth of 20-25 m, this cage provides a culture volume of about 50 000 m^3. At a density of roughly 2-3 kg/m^3, up to 130 tonnes of fish can be stocked in each cage (Agius 2002).

The rapidly growing practice of bluefin capture-based aquaculture in the Mediterranean has created a series of difficulties for the estimation and reporting of related fishery statistics. At present, fishery statistics are based on catches, while production from capture-based aquaculture is prepared from export data. The primary reason is the lack of accurate estimates for the total weight and size composition of the catch. The problem is due to the transfer of live fish caught from the wild, and the solutions proposed so far (e.g. the use of underwater cameras to count the transferred fish) are not very precise. Therefore, the average weight of the bluefin tunas caught is only a rough estimate, made in order to calculate the total weight of the fish transferred to the cages. There is also a lack of information on growth and conversion rates in cages. At present, ICCAT estimates for the gain in weight of tunas during the capture-based aquaculture period is an average of 25% of their body weight. This leads to a conversion factor of 0.8; this is applied to farmed products imported by Japan to back-calculate capture weight.

Capture-based tuna aquaculture in Mexico and the USA

Tuna farming began in 1996 in Mexico, where it currently produces 3% of global output. The majority of operations are located on the Pacific side of the Baja Peninsula (Sylvia, Belle and Smart 2003). Typical size at capture ranges from 15-45 kg, and weight gains can range from 30-90% of initial weight with the production cycle typically being 3-6 months, as in other parts of the world. Mexican farming operations have grown from less than 50 tonnes/year to 600 tonnes/year during the last five years. The original farms were Mexican owned and operated, but the current production companies are various combinations of Mexican, Australian and Japanese partnerships. Fourteen new tuna lease applications were under review in Mexico in 2002.

In 2002, investigations were in progress for the development of tuna farming off the west coast of the United States - particularly in southern California - and also off the coasts of Hawaii (Sylvia, Belle and Smart 2003).

Capture-based tuna aquaculture in Australia

Australian operations started in 1990 near Port Lincoln (South Australia) and, by 2002, had developed into the largest farmed seafood sector in Australia (Clarke 2002). The development of the southern bluefin tuna capture-based aquaculture industry became possible due to collaboration between the Tuna Boat Owners Association of Australia (TBOAA), the Japanese Overseas Fishery Cooperation Foundation and the South Australian Government.

The trend in Australian capture-based tuna farming production from 1992-2001 is shown in Figure 93. Production figures reflect culture periods spanning two years, and consider harvesting strategies that vary from three to ten months after capture. In 2000/2001, harvest volume peaked at 9 050 tonnes (Clarke 2002), representing almost 40% of the global capture-based aquaculture production of tuna at that time (Figure 88). By 2002, the industry consisted of about 16 commercial companies. Southern bluefin tuna weigh 15-25 kg at capture, and are harvested progressively from the cages after 3-10 months. The average weight increases by 10-20 kg over the culture period (Clarke 2002).

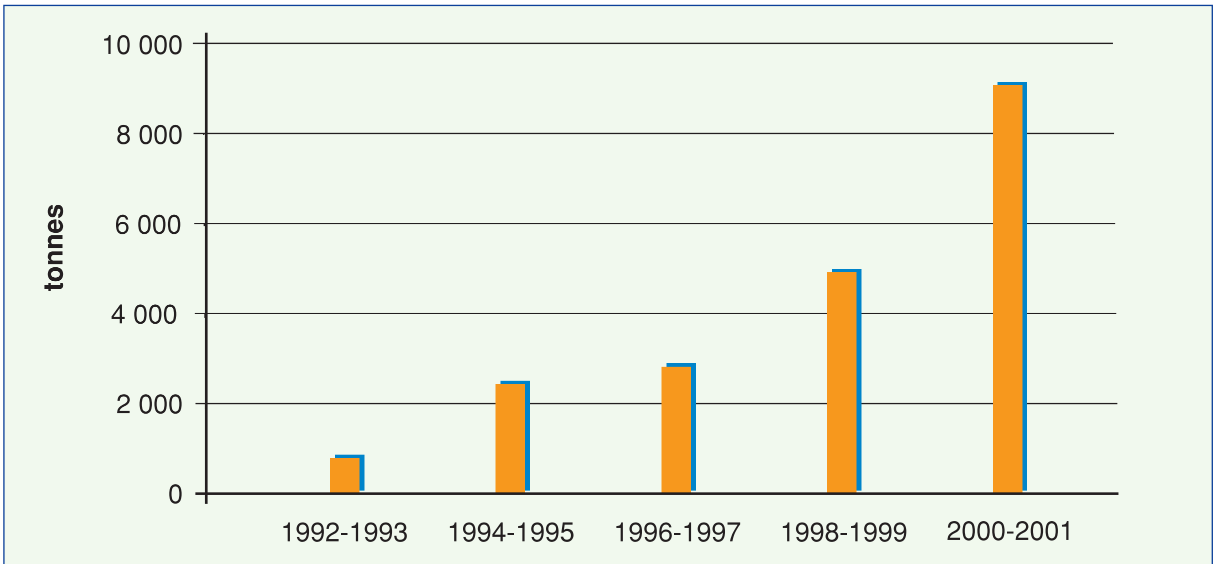


Figure 93. Australian production of southern bluefin tuna *(Thunnus maccoyii)* through capture-based aquaculture [Note: production data span the period between October and September the following year]

Capture-based tuna aquaculture in Canada

In 1975, American enterprises and Japanese specialists started capturing (with the trap system) and farming the bluefin tuna entering the St. Margaret Bay (Nova Scotia). Production was quite high in the period 1973-1978 – a maximum of 948 tonnes was achieved in 1977; however, only 72 specimens were captured in 1979. In 1980-1982 127 tuna were produced but in 1983 only 17. From 1984 captures were close to zero. Production started again in 1993 with 29 tonnes, and increased to 78 tonnes in 1994 (Table 45). The importance of an accurate knowledge of the ethology of the species is fully demonstrated by the Canadian fishing practice for capture-based aquaculture. Following some years of commercial success, a sudden change in the migratory pattern of northern bluefin tuna, due to hydrological changes in the warm current flowing into the Bay, led to the closing down of the business.

Table 45. Production of capture-based tuna aquaculture in Canada

Year	Average production (tonnes/year)
1964-1972	401
1973-1978	630
1984-1990	0
1993	29
1994	78

Culture systems

The culture systems used in tuna capture-based aquaculture owe much to the development of the salmon industry. Offshore cage systems predominate for culture and towing operations. All those used have to be able to withstand rough sea conditions, and are some of the largest cages currently in used in mariculture.

Bluefin tuna capture-based aquaculture uses a similar culture system throughout the world (Figure 94), due to common fish behaviour and environmental requirements. Beaz (2003) states that a good tuna cage should be designed to be deep enough to allow normal tuna behaviour and to avoid the stress mortality caused by lightning during storms.

The cages are typically large (average diameter 30-50 m), to allow large tuna enough room for movement, and are floating (submersible cages are also being tested). The circumference of the cages are typically 150 m and the fish are usually stocked at densities of about 2-4 kg/m^3. Some companies are now using much larger cages, with a circumference of about 270 m, giving a culture volume of 150 000 m^3. There is already evidence mounting that the larger the cage, the better the fish quality (Agius 2002). Cages need to be moored in water that is of sufficient depth to allow good flow patterns beneath the cage, and so that any waste build-up beneath them cannot interact with the water within them. A minimum of 20 m clearance is recommended by Agius (2002). Cages are usually made from high density polyethylene material which is flexible but at the same time strong enough. There are many versions. There are also cages which consist solely of nets with no surface collar (Agius 2002).

Figure 94. Tuna cage in Port Lincoln (South Australia) (Photo: L. Mittiga)

Good water quality is crucial for bluefin tuna, and suitable locations should exclude any possibility of turbidity caused by runoff or the stirring of benthic material. In Morocco, heavy storms caused a high number of deaths among bluefin tuna kept in a very large rearing cage: the gills of the fish were found to be clogged with mud, due to floods in the area (Mourente and Pascual 2002). Experience gained in tuna farming so far particularly emphasises the importance of choosing suitable locations, which should ensure that the open sea dominates the dynamics of the water column in which the cages are located, thus ensuring high transparency and high dissolved oxygen, which sustains the high physiological demand and continuous energetic swimming costs (Katavic, Vicina and Franicevic 2003a). Doumenge (1999) estimated that the optimum temperature for tuna is between 18 and 26°C, but tuna can also suffer from reduced salinity and the presence of suspended particulate matter.

Specific cage designs differ widely in the construction materials used, their mooring systems and the mesh size employed for the net. Some accounts of differing systems follow. In Morocco, fish are kept in 120 x 40 x 30 m floating net-cages moored in the open sea that has a depth of 55m (Nhhala 2002). Farms currently (2002) in operation in Malta stock their fish in a total of thirteen 45–60 m diameter offshore cages that are anchored 1 km off the coastline. The cages are high density polyethylene (HDPE) floating circular cages and are moored independently (Peric 2003b). In Croatia, cages are situated mainly along the eastern central Adriatic coast. The cage type developed in Australia, though slightly modified, is used for holding the fish: the floating circle cage has a diameter of 50 m and a net depth of 20 m (Katavic, Vicina and Franicevic 2003b;

Miyake *et al.* 2003). They are only partially anchored, and can be moved from one location to another. Bridgestone or Dunlop (rubber hoses) floating cages are used in Cartagena, Spain (Doumenge 1999). Old Japanese rectangular type of cages, about 70 x 40 m, anchored to the bottom of the sea, are used in Ceuta, Spain.

The tuna capture-based aquaculture industry in Australia uses twenty 20-30 ha lease sites (in 2002) in wave exposed waters from 1-10 km offshore in about 20 m water depth (Clarke 2002). 40 m diameter Polar-Cirkel HDPE cages are used, with a total volume of 15 000 m^3 (Doumenge 1999). Since 1996, larger cages (with a diameter of 50 m) are in use, for a total volume of 20 000 m^3. Mesh sizes vary between 55 mm to 70 mm (O'Sullivan 1993). In Amami O-shima (Japan), the cages rely on a buoy system that assures both floating and structural integrity. The cages are rectangular, 40 x 25 m but are only suitable for use in sheltered waters.

Turner (2002) believes that tuna capture-based aquaculture culture systems are in need of improvement. Engineering should focus on the construction of larger cages that are able to survive the offshore wave climate with very little maintenance, and that can be moored in very deep water. The basic technology for cage construction of this type exists and has been tested in Norway and other salmon producing nations; however the cost implications and maintenance of mooring systems for cages in very deep waters needs careful evaluation. Turner (2002) proposes solutions such as a tension leg mooring system, increased automation, and electronic monitoring transmitted by telemetry. Offshore cages require larger boats to service them (Figure 95). Daily hand feeding routines may thus become impractical but fish health and water quality would definitely improve if they were feasible. However, repairing and cleaning nets, and routine husbandry and maintenance activities could be more difficult and more costly if larger cages and more deep water locations are introduced.

Figure 95. Offshore cage for the capture-based farming of tuna (Photo: L. Mittiga)

Feeds and feeding regimes

Information on feeding strategies, feed conversion ratios, etc. is limited, mostly referring to Australian farming practices. Here the fattening period is short, varying from 3 to 10 months. Fat levels show a decline over winter months, supporting the fact that the summer growth produces better quality fish. The farmed southern bluefin tuna are fed baitfish (Figure 96) six days a week, twice a day. The feed is generally presented by placing the frozen blocks of baitfish (pilchards, herrings, mackerel, squid) in a mesh within each cage. Supplementary feeding is generally done by hand. In 2001 some 20 species and about 45 000 tonnes of baitfish were used, sourced locally and overseas (about two thirds of this being imported, primarily from the USA and northern Europe). Typically, over a farming season, food conversion ratios are about 10-15:1 using baitfish. The average size of the southern bluefin tuna increases by 10-20 kg, and mortality rates are between 3-7% (Clarke 2002). Conversion ratios vary with the culture season (10:1 in summer time and 17:1 in winter time) and with tuna size – smaller tuna have better FCRs than larger ones (O'Sullivan 1993).

Figure 96. Frozen blocks of baitfish for capture-based tuna aquaculture (Photo: L. Mittiga)

The most pressing research goal of the Australian tuna farming industry has been the development of manufactured feeds to replace the use of baitfish (Montague 2003). Continuous quality improvement is compromised by the need to use a wide variety of baitfish, which have a correspondingly wide range in quality. It is not the quantity of baitfish supplied to the tuna that influences production, but the supply and quality of nutrients obtained from consuming them. If baitfish are low in protein and fat, then tuna growth will be retarded, and greater quantities of baitfish will be required to maintain the same production level. The suitability of the baitfish also depends on storage history and the standard of quality control. The characteristics of the baitfish used in tuna production varies significantly. A survey undertaken in 2000 revealed large variation in the crude protein, crude fat, free fatty acid and peroxide values present in baitfish samples (Table 46).

Table 46. Baitfish composition (www.sardi.sa.gov.au)

Parameter	Range
Crude protein (% DM)	49.4 - 75.3
Crude fat (% DM)	1.9 - 36.5
Free fatty acids (% DM)	2.9 - 53.4
Peroxide value (meg/kg DM)	< 0.1 - 598.0

The southern bluefin tuna is an important mariculture species in Australia but the development of manufactured feeds has been limited, due to the lack of detailed information about their nutritional requirements (van Barneveld *et al.* 1997). Although pelleted feeds have been developed, progress has been slow. The development of a formulated pellet for replacing baitfish is still in progress; however, there are difficulties in conducting large-scale growth trials (because of the scale of the cages necessary and the value of the experimental fish) to evaluate their quality (Bransden, Carter and Nowak 2001). Often Atlantic salmon, *Salmo salar*, are used in screening experimental feeds, as a "surrogate" species (Carter *et al.* 1999; Bransden, Carter and Nowak 2001) in nutritional research on southern bluefin tuna. However, this has its limitations, since salmon have different life strategies and different nutrient requirements, so that it is unlikely that the resulting diets will be optimal for tuna culture.

Encouraging results were obtained in 1997-1999 in South Australia through a small-scale research project on the tuna research farm of SARDI, in conjunction with the CRC for Aquaculture. A manufactured feed substituted for pilchard feeds (Figure 97) provided comparable growth rates, product quality and market price. Problems regarding sub-optimal acceptance and palatability of pellet feeds by the southern bluefin tuna, production costs and possible Japanese market resistance to fish reared on pelleted feeds, were some of the reasons cited why farmers were reluctant to evaluate the recommended manufactured feed in their commercial farms. In a trial

Figure 97. Baitfish feeding for capture-based tuna aquaculture

performed in 2001, two groups of tuna were fed exclusively on manufactured feed and the results compared to those obtained by tuna fed on baitfish. The fish, later harvested for sale in Japan, grew on the pelleted diet (40% protein; 20% oil), displayed longer flesh shelf-life and gained average prices of ¥ 3 027/kg (www.sardi.sa.gov.au); an FCR of around 10:1 was obtained with baitfish, while the use of mixed pelleted feed achieved an FCR of about 2:1 (B. Jeffriess, pers. comm. 2002). SARDI (South Australian Research and Development Institute) research now focuses on improving the palatability of the pellets and improving feed management techniques to optimise FCR (www.sardi.sa.gov.au); Australian researchers are also working on extruded pellets.

In the Mediterranean area tuna are also fed baitfish. In the work of Katavic, Vicina and Franicevic (2003a) tuna were fed for the first time nine days after being stocked. They were given raw, defrosted small pelagic fish, mostly (87.9%) herrings (*Clupea harengus*); the remaining feed was composed of raw defrosted sardines, *Sardina pilchardus* (6.7%) and cephalopods (5.4%). Feed was distributed six days per week, twice a day, in the morning and the late afternoon. The daily feeding rate gradually increased until the end of July, when the tunas were fed with a daily feed quantity equalling to 7.7% of their biomass. According to feeding records, which covered the culture period of 155 days, it was calculated that the tunas were given a total of 399 005 kg of feed. The maximum daily feeding rate was 9.8%, and the average daily feeding rate was approximately 5.1% of the total fish biomass (Katavic, Vicina and Franicevic 2003a). Unfortunately the FCR value was not reported in this paper. In Croatia, small pelagic fish are used (e.g. frozen herrings *Clupea harengus*, pilchard *Sardina pilchardus*, round sardinella *Sardinella aurita*, and short-fin squid *Illex coindetii*) at approximately 5-8%/day of estimated biomass during summer season. In 2001 about 15 000 tonnes of baitfish were used, sourced both from the North Sea and locally (Katavic, Vicina and Franicevic 2003a,b). During the fattening season, bluefin tuna are normally overfed and food conversion ratios are about 15 to 20:1. The highest feed consumption occurs at 23-25°C, with up to 10% of body biomass being fed daily; this may be reduced by half at 20°C and daily feed consumption does not exceeding 2-3% of body weight at 18°C (Katavic, Vicina and Franicevic 2003b).

An experiment using a submersible cage was conducted in Italy, in the central Adriatic sea, four marine miles off Ortona; during the four month culture cycle the daily feed ration consisted of sardines, squid (in small percentages due to their high cost) and mackerel at a daily rate that averaged 5% of the biomass inside the cage. Tuna were fed with a total of 4 376 kg of baitfish; the species used and their relative percentage are shown in Table 47. At stocking, the average weight of the tuna was 3.8 kg; after 4 months it had reached 10.8 kg. Feeding behaviour was not influenced by depth: as soon as the cage was brought to the surface, the fish responded immediately to feeding in the same way that they would have with a cage permanently moored in proximity to the surface. The underwater feeding tests showed that depth did not effect fish appetite.

Table 47. Quality and relative percentage of the fish utilized for feeding the tuna in Ortona (Italy)

Species	Total weight (kg)	%
Boops boops	1 968	45.0
Sardinella aurita	1 096	25.0
***Illex* sp.**	511	11.7
***Scomber* sp.**	305	7.0
Other species	496	11.3

Tuna are fed on Mediterranean frozen fish (e.g. herrings, sardines and mackerel) in Malta. According to (Peric 2003b), each cage was fed 1 509±361.6 kg and 1 099.3±79.0 kg of frozen feed per day during August and September respectively. The 2000 farming season in Murcia (Spain) provided the data shown in Table 48, which illustrates the weight increase of farmed tuna achieved (the length of the culture period was not reported) (Cunningham and Bejarano 2002).

Table 48. Percentage increase in weight of farmed tuna in Murcia (Spain)

Cage number	Mean final fish weight (kg)	Mean initial fish weight (kg)	% increase in fish weight (%)	Maximum cage density (kg/m³)	Mean daily consumption (g/kg)
1	190.29	143.70	32.42	4.11	26.9
2	175.92	132.74	32.52	4.51	31.2
3	158.32	126.63	25.02	2.73	30.1
4	160.00	150.93	6.00	5.73	37.5
5	Unknown	77.09	Unknown	0.29	31.2
6	120.92	99.33	21.73	3.67	33.1
Average	161.09	130.67	23.28	4.14	32.3

An experimental farm in Morocco was fed “trash fish” – Atlantic mackerel, horse mackerel and short-fin squid. Two batches were kept in floating cages: the first batch comprised 75 giant bluefin tuna (mean body weight around 250 kg) and the second one contained 106 young bluefin tuna (mean body weight about 55 kg). The feeding behaviour of the tuna showed seasonal changes, which were particularly evident in the smaller bluefin tunas. Higher feeding activity occured in October-November and less in June-July. Feeding selectivity showed that giant bluefin tunas prefer squid, while younger bluefin tuna favour Atlantic mackerel. The size of the fish was greatly affected by samplings and mortality during the winter season. The bluefin tuna also showed a seasonal growth pattern. The annual mean rate of growth was high (50 kg/year) for the giant bluefin tuna and 75 kg/year for the young bluefin tuna (Nhhala 2002).

An experiment was undertaken by a group of scientists headed by Teruo Harada in the fisheries laboratory of Kinki University, Japan in 1990. The tuna weighed 250 g at the time of stocking, and reaching 110 kg after 10 years and 145 kg after 15 years. The largest tuna was 177 kg and 229 cm long at 16 years old. The fish were fed mackerels, horse mackerels, anchovies and cuttlefish (Norita 2003). The development of the rearing technology for capture-based fingerlings in Japan has been successful to some extent. If the supply of farmed fingerlings (10 cm to 20 cm in length) can be kept stable, commercial tuna aquaculture becomes practical; FCRs of 10:1 have been achieved. Juveniles are captured by angling and on-grown in large floating cages. When conditions are stable, and the ambient water temperature remains above 15°C, mortality is low and growth is exceptional. According to Nash (1995) young fish, when captured, weigh between 100-200 g, but can attain 6 kg in one year, 20 kg in two, and over 60 kg in four years, depending on the feed availability, water quality and temperature. In captivity, the diet provided for bluefin tunas is similar to that for yellowtails, comprising of the available resources (squid, small scombroids, and trash fish). Feed conversion efficiency is better in younger fish, however. The ratio of wet weight of feed to weight gain was about 8:1 in the early months of growth, but increased to about 12.5:1 by the time fish reached 3 years of age.

One of the most important challenges in tuna capture-based aquaculture remains the development of a feed capable of substituting for baitfish. Raw fish diets have some inherent disadvantages, e.g. high food conversion ratios (Table 49), the risks of pollution and disease, and variable quality; these problems promoted the research into manufactured feed for farmed tuna. The manufactured feeds developed so far have focused on moist and semi-moist feeds; however dry feeds have also been accepted. Diet formulation development has been largely based on muscle composition and natural prey species (Smart, Sylvia and Belle 2003). These studies, not unexpectedly indicate that tuna need a high energy, high protein, low carbohydrate diet, typical of a high order, opportunistic carnivore. Nevertheless, the current rearing systems are based on the growing of wild animals (Essed *et al.* 2003), which makes their adaptation to inert diets difficult.

Table 49. Summary of reported types of feed anad FCR reported in capture-based tuna aquaculture

Country	FCR	Type of feed	Reference
Australia- winter cycle	17:1	Baitfish	O'Sullivan (1993)
Australia – summer cycle	10:1	Baitfish	O'Sullivan (1993)
Australia	15:1	Baitfish	Clarke (2002)
Mediterranean area	15-20:1	Baitfish	Katavic, Vicina and Franicevic (2003b)
Japan (fingerlings)	8:1	Baitfish	Nash (1995)
Japan (juveniles)	12.5:1	Baitfish	Nash (1995)
Australia (experimental)	2:1	Mixed semi-moist pellet	B. Jeffriess (pers. comm. 2002)

Given the high volumes of baitfish needed to feed tuna, there is a potential negative affect on the associated fisheries on small local populations (see Chapter 3). New feeds and feeding regimes are urgently needed for the further development of tuna capture-based aquaculture. Collaboration between the industry and research scientists must be the basis for projects to develop artificial diets that can achieve better feed conversion ratios and control meat quality and the relative production costs of this type of aquaculture.

Fish health and disease

Knowledge of microbial, nutritional and environmental diseases of cultured bluefin tuna is limited. However, adult tunas appear to be relatively resistant to bacterial infections, even when subjected to trauma and other factors that predispose them to such infections (Munday *et al.* 2003). Table 50 shows the principal pathogens that infect bluefin tuna; more details are provided in Munday *et al.* (2003).

Table 50. Specific pathogens of bluefin tuna

VIRUSES
Iridoviruses
→ Red seabream iridoviral (RSIV)
BACTERIA
→ *Aeromonas* sp.
→ *Caligus elongatus*
→ *Vibrio* spp.
→ *Photobacterium damsela* subsp. *Piscida*
→ *Mycobacterium marinum*
PARASITES
Protozoa
→ *Goussia auxidis*
→ *Uronema nigricans*
Myxosporea
→ *Kudoa clupeidae*
→ *Kudoa* sp.
Monogenea
→ *Benedenia seriolae*
→ *Caballerocotyla* sp.
→ *Hexostoma* sp.
→ *Metapseudaxine ventrosicula*
→ *Nasicola* sp.
→ *Neohexostoma* sp.
→ *Sibitrema poonui*
→ *Tristomella* sp.
Digenea
→ *Anaplerurus thynnusi*
→ *Aponurus lagunculus*
→ *Atalostropiom sardae*
→ *Bucephalopsis sibi*
→ *Cardicola* sp.
→ *Cetiotrema crassum*
→ *Celiotrema thynni*
→ *Colocyntotrema* sp.
→ *Didymocylindrus filiformis*
→ *Didymocystis* sp.
→ *Didymocystoides semiglobularis*
→ *Didyimoproblema fusiforme*
→ *Didymozoon* sp.
→ *Distomum clavatum*

- *Hirudinella* sp.
- *Koellikerioides orientalis*
- *Köllikeria* sp.
- *Lescithaster gibbosus*
- *Lecithocladium excisum*
- *Lobatozoum multisacculatum*
- *Nematobothrium* sp.
- *Oesophagocystis* sp.
- *Prosorhynchoides sibi*
- *Rhipdocotyle* sp.
- *Sterrhurus imocavus*
- *Syncoelium filiferum*
- *Wedlia* sp.

Cestoda

- *Callitetrarhynchus gracilis*
- *Grillotia* sp.
- *Lacistorhyncus tenuis*
- *Nybelinia lingualis*
- *Pelichnibothrium* sp.
- *Tentacularia coryphaenae*
- *Tetraphyllidean larvae*

Nematoda

- *Anisakis* sp.
- *Contracaecum* sp.
- *Heptachona caudata*
- *Hysterothylacium* sp.
- *Oncophora melanocephala*
- *Spriurida*

Achantocephala

- *Bolbosoma vasculosum*
- *Neorhadinorhyncus nudus*
- *Rhadinorhyncus pristis*

Copepoda

- *Brachiella thynni*
- *Caligus* sp.
- *Euryiphorus brachypterus*
- *Pennella filosa*
- *Pseudocynus appendiculatus*

Young Pacific bluefin tuna are often infected with "red seabream iridovirus" but the disease never appears in those that are more than 1 year old. Sometimes mortality reaches 10% for young fish (Munday *et al*. 2003). Little was known about the health aspects of southern bluefin tuna when capture-based aquaculture began in 1990. Although it is probable that tuna can and do suffer from many of the commonly reported fish diseases, experience of them is limited, and treatment nearly impossible, due to the size of the cages used and the susceptibility of tuna to stress. It is known that water quality and general cleanliness are essential for tuna health. *Aeromonas* sp. infections have been reported in association with *Caligus elongates* damage to the eyes of southern bluefin tuna (Munday *et al.* 2003).

For several years, low levels of mortalities were recorded with an unexplained cause, subsequently identified by the late Dr Barry Munday in the University of Tasmania as the ciliate protozoan *Uronema* (www.sardi.sa.gov.au). The scuticociliate *Uronema nigricans* is an opportunistically parasitic marine ciliate known to cause disease in some aquacultural environments (Crosbie and Munday 1999). Parasitological and histological findings suggest that the parasites initially colonise the olfactory rosettes and travel along the olfactory nerves to invade the brain. Possible epidemiological factors involved in the pathogenesis of this disease include low water temperature (<18°C) and the immune status of the fish (Munday *et al.* 1997).

A parasitic blood fluke (Digenea: Sanguinicolidae) was identified in farmed tuna in South Australia in 1997 and was subsequently described as *Cardicola forsteri* (Cribb *et al.* 2000). Southern bluefin tuna are a new host species for blood flukes and *C. forsteri* is a newly described species (Colquitt *et al.* 2001). It was unclear if this blood fluke was causing a significant problem within the industry. Blood flukes are known to cause significant pathology in several other maricultured species (e.g. cultured seabass (*Lates calcarifer*) in Malaysia) and have caused mass mortality in Japanese amberjack juveniles, as reported by Ogawa and Fukudome (1994). Generally, the pathology observed in cultured southern bluefin tuna was not considered to be severe enough to lead to mortality. Histological examinations for eggs of *C. forsteri* included gills, heart ventricles and other organs collected from wild and captive southern bluefin tuna. In infected farmed fish, fluke eggs impacted in the afferent filamentary blood vessels where they provoked a marked but variable inflammatory response, resulting in nodular gill lesions (Colquitt, Munday and Daintith 2001).

In April-May 1996 an extensive mortality was observed in Boston Bay (Port Lincoln, South Australia), where approximately 75% (1 700 tonnes) of the fish died. This coincided with an ocean surge and strong winds. Clinical symptoms included distress, while some of the dead fish showed large quantities of mucus flowing from their gills. Possible aetiological factors were considered to be microalgal toxicosis, hypoxia, smothering by suspended solids and hydrogen sulphide toxicity (Munday and Hallegraeff 1997). The ichthyotoxic raphidophyte flagellate *Chattonella marina* was successfully cultured from Boston Bay (South Australia), and could have been consistent with this mass mortality of southern bluefin tuna (Marshall and Hallegraeff 1999).

The use of oily baitfish as a source for captive tuna poses a number of problems. The presence of thiaminases [see note on thiamine on page 137] and oxidized lipids in baitfish has been, or is likely to be, responsible for nutritional problems in tuna (Munday *et al.* 2003). Indirect problems can occur when parasites (e.g. *Kudoa*) are present in trash fish (e.g. sardines); appropriate freezing procedures decrease the risk, as this kills all of the parasites (B. Jeffriess, pers. comm. 2002). Benign parasitical infestations are more common in the summer, when the warmer water temperatures that are especially important for tuna cultured in southern latitudes exist. Parasitic worms are rarely found in the flesh and though completely harmless to humans, the pin head sized white eggs they deposit are evidence of their presence and can severely affect the price of the tuna when sold to "*sushi*" restaurants.

The storage of the baitfish utilised for feeding tuna in captivity needs special attention. One study showed that in chilled storage the pilchards exhibited obvious deterioration within two days. Substantial peroxide values were found, and oxidised odours and flavours were clearly evident, after 4 days of chilled storage. In frozen storage, oxidation occurred after only one month at a temperature of -20°C. Pilchards in which oxidation had commenced before freezing continued to oxidise in frozen storage (Fitz-Gerald and Bremner 1998). It was demonstrated that the oil in the pilchards readily oxidises; careful handling, chilling, freezing and storage procedures need to be adopted to provide a product that is nutritionally sound for captive tuna. Baitfish are also known to carry important viral diseases such as viral haemorrhagic septicaemia and pilchard herpes-virus (Munday *et al.* 2003).

In the early stages of Pacific bluefin tuna aquaculture in Japan, morbidity and mortality was reported to be caused by a shortage of thiamine [this is the most common form of vitamin deficiency in fish nutrition and is especially prevalent when raw aquatic animal products are used as feed, either solely or in combination with other ingredients (New 1987). This is particularly so when diets containing raw fish are not fed immediately after capture or manufacture, because thiaminase may partially or completely deactivate the thiamine originally present]. Some fish contain particularly high levels of thiaminase. At that time only Pacific saury (*Cololabis saira*) and/or Japanese anchovy (*Engraulis japonicus*) were fed to the tuna in Japan, resulting in a large reduction of the thiamine stores of the cultured fish. Now, several kinds of baitfish are fed to tuna in Japan and this disease no longer occurs (Munday *et al.* 2003).

During the processing and packing of harvested tuna in Malta, extracted organs were examined for any abnormalities or tissue changes. The organs examined (spleen, liver, stomach, intestine and kidney) were considered more as an indication of fish health status, since there was no evidence of morbidity (Peric 2003a).

Significant disease related mortality is best prevented by recognising and decreasing risk factors before they become a major problem. The Aquafin CRC, a strategic and proactive project in Australia (Aquafin CRC, 2001a,b,c,d,e,f) focuses on the development of tuna cell lines in order to have the capacity to culture viruses if these were to prove an issue in the future, either as part of grow-out activities or in the hatcheries as part of southern bluefin tuna propagation. It is a very important project because it provides, for the first time, a comprehensive review of the potential southern bluefin tuna health issues based on relevant published information and the existing tuna health database of the TBOASA (Tuna Boat Owner Association of South Australia). From this review it is intended that a qualitative assessment of the types of health risks and their potential impacts shall be tabulated, and recommendations made in regard to the likelihood/priority of the potential issue and R&D strategies appropriate to address them. The project started at the beginning of February 2002 and was expected to be completed at the beginning of May 2003. The main objectives were:

- to provide a qualitative fish health risk assessment for the tuna aquaculture industry in Australia;
- to review tuna health information and databases from the industry, research organizations and scientific literature;
- to identify areas of higher risk and propose management control measures for the industry, as well as research priorities; and
- to circulate the results of this southern bluefin tuna health risk assessment project (www.sardi.sa.gov.au).

Harvesting systems

The products from the capture-based aquaculture of tuna are nearly all destined for the Japanese market, where they will be used mostly for "*sushi*" and "*sashimi*". To achieve the best prices in this specialist market, producers must harvest high quality tuna; this requires special care in the killing and handling of the fish during harvesting.

The criteria used to define high quality tuna are:

- a high level of freshness;
- signs of a fast bleeding of tuna after the kill;
- the absence of flesh burns due to lactic acid formation;
- the absence of, or a very low level of histamine; and
- a high fat content.

It is evident that harvest practices influence such quality attributes as freshness, fat content, colour and shape.

When bluefin reach the optimum weight and fat content, and when the market price is favourable, harvesting begins. In the Mediterranean area the fish are ready for harvesting by October. Some farms market all their fish by December; others linger on till February/March, depending on transport logistics. For instance, if air transport is a problem, the fish may have to be sold in frozen form rather than fresh (Agius 2002). Generally the processing volume targeting the frozen fish market depends on the daily blast freezing capacity of the ships. Once freezing is complete, the ships transfer the fish to a reefer ship which then goes to the Far East (Agius 2002).

In harvesting, bluefin tuna are typically crowded into a small area using a net, where divers capture them by hand – as in Croatia and in Australia (Figure 98).

Figure 98. Divers capture a tuna during harvesting in Port Lincoln, South Australia
(Photo: L. Mittiga)

Divers plunge into the cages, grab a tuna and immediately return to the deck of a floating structure. Here the tuna is killed with a spike to the brain [adult and giant bluefin tuna are usually killed by a shotgun (Mateo *et al.* 2003)] and then moved to the waiting boat, where they are cored (a wire passed through the neural canal) at the slaughtering table and left to bleed (Katavic, Vicina and Franicevic 2003a,b). If tuna are not handled in the correct way, their meat becomes "*yake*", which in Japanese means burnt. This happens when there is an accumulation of lactic acid and an increase of temperature, due to the muscular spasms that continue after death. To avoid this phenomenon it is important to manipulate the tuna carefully, in order to avoid continued muscle contractions, and to kill the fish in the least possible time – this is done by paralysing the neural canal, which assures good meat quality. It is also necessary to leave the fish bleeding, to maintain meat colour and consistency. The bleeding process is particularly important for fish that will be frozen, as it allows the transformation of myoglobin to met-myoglobin (Chiou *et al.* 2001); this gives the tuna its meat colour. Fish are then eviscerated and cleaned carefully with the aid of brushes, to remove any residuals that could deteriorate the meat. During all these procedures it is necessary to decrease the body temperature of the tuna, to maintain meat quality. Cooling extends the time before the onset of *rigor mortis*, but this is also very dependant on fish size. Cooling methodologies vary, e.g. in Australia during harvesting, bluefin tuna are placed big "fish room" tanks, filled with slush ice and sea water of about -2°C.

Post-harvest activities depend on whether the tuna are to be exported to the Japanese market by plane or ship. Fish can be shipped fresh or frozen. In South Australia, 200 individuals are usually harvested in a single day. A Japanese biologist is always present to control the muscle quality of the fish, and no fish will be purchased if the muscle is burnt. The bluefin tuna are then directly taken to Japanese (or Korean) boats, where the fish are cleaned and frozen to -60°C. It is the killing, more than anything else, that influences the quality of the tuna meat. Fish that have struggled during the slaughter will have a less pink or reddish meat, which makes their market price lower (Katavic, Vicina and Franicevic 2003a).

In the Mediterranean area, an electric stunning technique is used to harvest fresh fish. Two methods are used for harvesting for the frozen fish market. One method is to introduce a smaller net into the fattening cage to crowd the fish, which can then be taken out slowly (Figure 99). There is also a method where a small square cage with a V-shape at one end is used; this has an open window which allows fish to swim in. As the fish swim into the cage, workers standing on a floating platform pull the net up and, at the same time, move to the V-end of the harvest cage to crowd the fish (Agius 2002).

Spanish farmers have been experimenting with an important technological advance for the tuna mariculture industry: a new procedure for killing tuna. Electro-fishing techniques are already utilised but additional research is necessary to improve electro-slaughtering techniques, and to develop specially designed equipment (Mateo *et al.* 2003). At present, a diver selects the fish to harvest and, with the aid of a gun, injects a small electric harpoon. A second diver checks that the harpoon has reached its target and then induces an electric discharge of approximately 100 volts. This stuns or kills the fish. A new system could be developed in order to remove the need for the divers, and minimise the "pre-mortem stress" for the fish by regulating the electric discharge, in relation to their size (Crespo *et al.* 2002).

In fact, pre-mortem stress is a very important factor in sea food quality. Oxidative stress research is under way, and stressed fish have been seen to be more vulnerable to disease, due to an impairment of their antioxidant defence system (Ferrante *et al.* 2003). This is particularly important where partial harvesting is normal e.g. in tuna farming. Automation may help in the development of effective quality-assurance methods. According to Roca *et al.* (2003) each fish should be tagged after slaughtering by means of an electronic transponder containing a chip capable of recording multiple data such as weight, dimensions, capture details, and processing instructions.

Harvesting techniques will continue to develop so that the products from tuna capture-based aquaculture can meet the exacting standards of premium markets.

Figure 99. Transfer of tuna for harvesting (Photo: L. Mittiga)

Marketing

Bluefin tuna are regarded as a high-grade product in Japan and are involved in an unusual marketing system, by seafood industry standards. Each fish is individually inspected for various quality attributes before being flown to Japan for the fresh tuna market. In the Tsukiji market (the Tokyo Central Wholesale market, which is also the largest wholesale auction market in the world for tuna), bluefin tuna prices are determined to a large extent by grade or attributes (Carroll, Anderson and Martinez-Garmendia 2001). The weight of individual fish can affect pricing because of the economies of scale associated with transportation, and the consumer-ready product yield per size of whole fish. Their value is also a function of the relative quality of the individual fish (e.g. fat content) with respect to the available supply, the quantity of product available, and the concomitant presence of other types of tuna in the market.

The consumption of bluefin tuna depends strongly on the specific Japanese culture. Bluefin tuna is almost exclusively eaten raw in Japan. The four basic attributes on which fresh bluefin tuna traders rely to measure product quality are the freshness, fat content, colour and shape of the individual fish. Brokers in the United States and auction market officials in Japan grade these attributes from A-E (A representing the highest and E the lowest possible grade) to assist Japanese wholesale buyers in their purchasing (Carroll, Anderson and Martinez-Garmendia 2001). Traders are observing the gradual development of a niche market for "*sashimi*" in the United

States, and are using Japanese restaurants as a channel for distribution there. This is a result not only of the increasing popularity of raw fish among American consumers, but also of the recent weakening of the Japanese Yen relative to the US dollar (Carroll, Anderson and Martinez-Garmendia 2001) and the economic crisis in Japan.

Farmed tuna are regarded as being in marketable condition after about 3-6 months of feeding. with the exception of those reared in Japan and Croatia, where fish are fattened for a longer time. The premiums achieved are generally based on freshness, high condition index and fat content (Smart, Sylvia and Belle 2003). The bluefin tuna is most appreciated by the Japanese consumer above all the other species, particularly the Mediterranean one. The price of bluefin tuna is double that of other "*sashimi*" tuna. The high demand is reflected in the price, which is generally the highest in the market, when compared to the other different tuna species.

The higher oil content in farmed tuna makes the product particularly suitable for "*sushi*", since the oil is absorbed by the rice. Farmed tuna from the Mediterranean has a higher oil content than its Australian equivalent, and it is more appreciated in Japan; the oil also gives the flesh a more reddish colour, which makes it more attractive (Tudela 2002b). Different parts of the tuna command different prices; the most appreciated part is the external 6-10 cm (called "*toro*"), of which the ventral sections (denominated "*chutoro*" and "*ootoro*") are the most valuable. The internal part ("*akami*"), is red and translucent. The bluefin tuna is the species which has the major quantity of high quality *toro*. *Toro* is graded by its fat content; in the past, the Japanese favoured leaner tuna, but in the last fifty years they have come to prize the tender, smoky taste of tuna with a higher lipid content. The word "*toro*" means "melt", alluding to its "meltingly tender, buttery rich texture". "*Toro*" is traditionally sliced thickly, ½ inch or more for "*sushi*" and ¼ inch for "*sashimi*", to allow its rich flavour and soft texture to be fully appreciated.

Northern bluefin are known by the Japanese as "*hon-maguro*" (a general term for the northern bluefin), "*kuro-maguro*" (*Thunnus thynnus thynnus*) and "*shibi-maguro*" (*Thunnus thynnus orientalis*) and they are considered the best for "*sushi*". Smaller "*meji*" (young bluefin tuna usually below 5 kg) are lighter and lack flavour, while the largest fish concentrate the distinctive tuna-flavoured oils. The deep red meat of "*minami maguro*" (*Thunnus maccoyii*) is richly flavoured but its quality varies considerably depending on the season (in the summer the fish reaches the highest fat content). Since both northern and southern bluefin reared in capture-based aquaculture became available in reasonable quantities, they started to constitute a middle quality category in the market, filling the gap between the two extreme categories of quality. Farmed tuna are now sold even in Japanese supermarkets and are used in the popular and inexpensive "*sushi*" bars such as "rotating *sushi* bars" (Miyake *et al.* 2003).

The Japanese market trend controls the right moment for selling capture-based aquaculture tuna products. The aim is to sell when the total volume of tuna products is low; this is not so simple, as it is difficult to predict when bluefin tuna coming from the fisheries will arrive in the market. Sometimes it is so unpredictable that the result is a price decrease (Doumenge 1999). Strategies adopted by the farmers are different, and sometimes only fresh red tuna is offered, but achieves good prices; the harvesting of a few specimens must be repeated in an effort to try to select the best days for the market. This implies high freight costs (by air) and the necessity for specialised staff.

In 2001, Mediterranean capture-based tuna for the frozen market were selling at € 20/kg, ex-farm. The prices for fresh fish are determined by auction prices in Japan, as well as airfreight charges. For the fish leaving Malta, the average prices are € 27-28/kg, because of the limited cargo space. For the fresh fish market, the fish are treated more or less individually and much more carefully. They have to be cooled down quickly, placed in boxes and then air-freighted

(Agius 2002). Mediterranean and Californian capture-based aquaculture products are present on the Tsukiji market in significant quantities (Table 51). Spanish tuna arrive at the end of October, followed one month later by the Californian/Mexican production, and two months later by tuna from Croatia. The Spanish industry ceases to ship tuna in February, while the Croatian and Mexican farms continue to export. Australian production is concentrated between April and October. Prices for the Australian products are lower than for the northern bluefin (*Thunnus thynnus*), and competition is also stronger with other tuna species (such as *Thunnus obesus*) (Doumenge 1999).

Table 51. Prices for fresh fattened bluefin tunas from the North Pacific and Mediterranean areas in the Tsukiji fish market (Doumenge 1999; INFOFISH 2003)

Dates	Spain		Croatia		Mexico		Japan	
	Pieces	¥/kg	Pieces	¥/kg	Pieces	¥/kg	Pieces	¥/kg
3/02/98	15	5 807	5	5 100	46	2 997	11	2 826
7/12/98	21	4 250	3	3 800	33	3 623	4	5 200
14/12/99	23	3 960	4	3 500	31	4 183	5	4 560
25/12/99	14	5 900	1	4 500	26	4 376	6	5 360
14/01/99	9	4 900	7	3 286	67	3 351	11	4 254
15/01/03		4 000-6 000				2 500-3 600		

It is interesting to compare the prices of bluefin tunas from different types of fisheries with those from capture-based aquaculture (Table 52). Longline and trap products gain the best prices, while those from aquaculture are much more valuable than those caught by purse seine.

Table 52. Arbitration prices for selling fresh North Pacific bluefin tunas in the Tsukiji market, compared to capture-based products (Doumenge 1999)

Dates	Long line		Purse Seine		Traps		Capture-based aquaculture	
	Pieces	¥/kg	Pieces	¥/kg	Pieces	¥/kg	Pieces	¥/kg
11/01/99	7	8 100	38	2 636	8	8 100	9	4 931
23/01/99	8	5 425	60	2 563	6	5 616	7	4 714
01/03/99	9	5 451	16	3 118	3	10 000	14	5 557
02/03/99	1	8 000	111	2 521	5	7 000	6	6 075

The Japanese market for bluefin tuna is expanding and the Tsukiji market in Tokyo is no longer the exclusive market for "*sushi*" products, having been joined by the Nagoya, Osaka (Table 53), Sendai, Sapporo and Tokyo-Chuo (Table 54) markets. One 200 kg bluefin tuna recently sold at auction in Japan for a record US$ 390/lb (Magnuson, Safina and Sissenwine 2001), and a giant bluefin tuna (>500 kg) caught in the Canary Islands was sold (ex-ship Las Palmas) for US$ 44 500; the airfreight bill from Las Palmas to Tokyo was an additional US$ 21 000 for an individual fish (J. Dallimore, pers. comm. 2002). Prices fluctuate wildly (Figures 100 and 101), emphasising the importance of selecting the best selling date.

Table 53. Spot prices for fresh bluefin tuna in the Osaka market, 3 October 2002 (www.fis.com)

Origin	Supply (pieces)	Minimum (¥/kg)	Maximum (¥/kg)	Average (¥/kg)
Canada	23	2 500	3 400	2 900
Japan	25	1 000	2 800	1 800

Table 54. Prices for fresh southern bluefin tuna (*Thunnus maccoyii*) in the Tokyo-Chuo market, 3 October 2002 (www.fis.com)

Origin	Supply (pieces)	Minimum (¥/kg)	Maximum (¥/kg)	Average (¥/kg)
Australia	5	1 800	4 600	2 650
Australia (farmed)	12	3 000	3 300	3 060

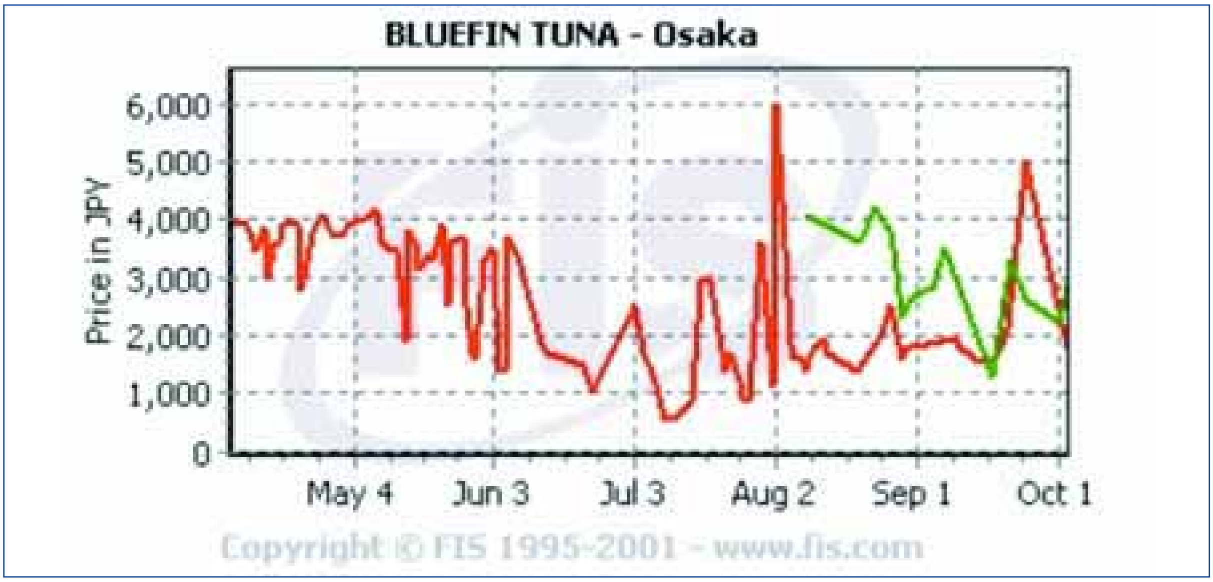


Figure 100. Average prices of fresh bluefin tuna in the Osaka market, May-October 2002
[Note: Red = from Japan; Green = from Canada]

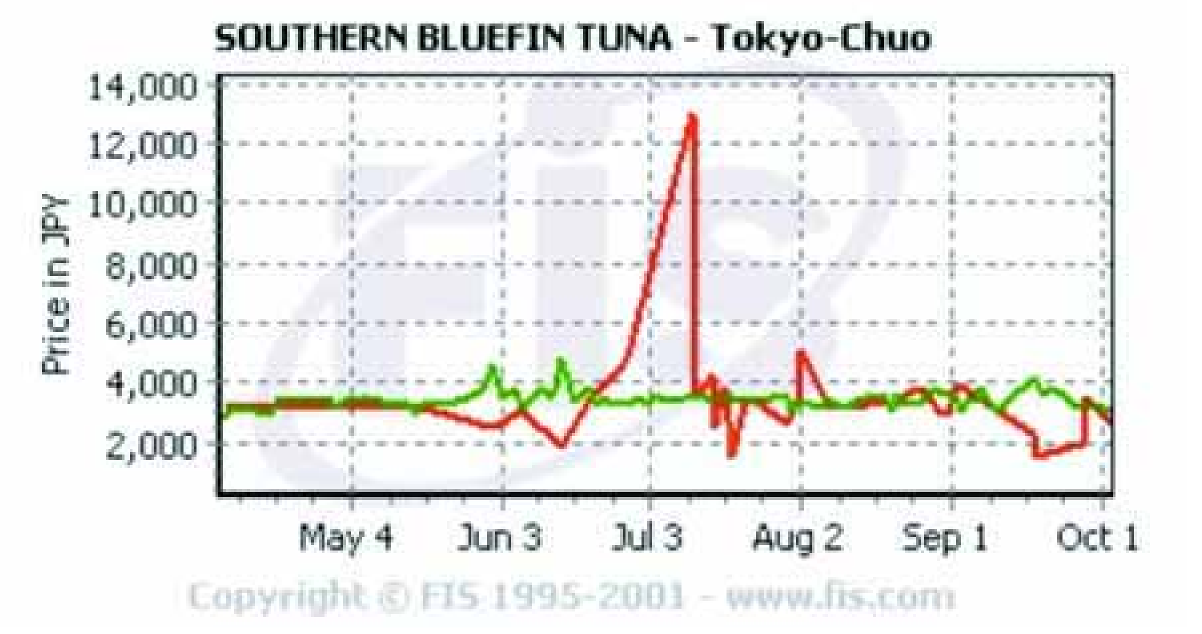


Figure 101. Average prices of fresh southern bluefin tuna *(Thunnus maccoyii)* in the Tokyo-Chuo market, May-October 2002 [Note: Red = from Australia (wild caught); Green = from Australia (farmed)]

The average price of fresh farmed southern bluefin tuna (Figure 101) is reasonably constant, while the price of the capture-based fish is more variable. This is mostly due to the guarantee of a good fat content for the fattened tuna. Extremes in the capture-based prices are often due to exceptional market conditions, or exceptional quality fish, which can command incredible prices.

The availability of imported frozen farmed tuna has increased, due to the explosion in capture-based aquaculture. A new technology that allows freezing to -60°C in a shorter period of time (30-40% quicker than the "Japanese freezer boats") is able to produce tuna that are of high quality, and can compete with fresh bluefin tuna on the market (FIS market report, 06/10/2002). Spain also exports some frozen farmed tuna to Japan, to be sold during February and March when the supply of fresh bluefin tuna is likely to be at its lowest (Miyake *et al*. 2003).

Although the Japanese economic crisis is still severe, the demand for both northern and southern bluefin tuna is always high. However, relying on a unique market (Japan) is becoming risky for capture-based aquaculture operators. The Yen devaluation in 2000 affected farmers' incomes (20% below 1999) and investments. Despite the fact that value of tuna remains high, the prices Japanese consumers are willing to pay continue to decline, and the Japanese economy reached new lows in 2002. Japanese consumers are also starting to change their consuming habits, choosing less expensive products (de Monbrison and Guillaumie 2003). There is also competition with other tuna species (big eye, yellow-fin) which are less expensive (€ 3-6/kg cif Japan, compared to € 20-40/kg for bluefin tuna). Nowadays, the operators of capture-based aquaculture of bluefin tuna farms are trying to expand their market beyond that of "*sushi-sashimi*", targeting consumers in other Asian countries, as well as the United States and Europe.

Conclusions

The capture-based aquaculture of tuna is expected to expand during the next few years, due to further technical developments and the market demand for its products. The long-term sustainability of the industry will depend on several factors:

- the reduction of baitfish utilization;
- the development of formulated feeds and reduced FCRs;
- improvements in feed formulation to ensure meat quality;
- the continued availability of “seed” material;
- the expansion of marketing activities away from reliance on Japanese markets;
- improved harvesting techniques; and
- improved offshore technologies for culture systems.

Environmental and ethical concerns (e.g. in the Mediterranean area) will continue to affect the functioning and image of the industry. Regulations are needed to create and control the traceability of products, as well as quality and environmental issues.

The prospect of achieving the captive breeding bluefin tuna, and being able to manage the complete life cycle, could represent a base from which the industry could further expand. This issue alone would remove ecological concerns and guarantee a sustainable future for the sector.

chapter 6

YELLOWTAILS

6

YELLOWTAILS

Introduction and species identification

The genus Seriola (family Carangidae, order Perciformes, class Actinopterygii) includes 47 species. In this report, three of these are considered: *Seriola quinqueradiata*, *Seriola dumerili*, and *Seriola lalandi*. In Japanese literature (e.g. Nakada 2000; Nakada and Murai 1991; Nakada, pers. comm. 2002), the English names of these fish are usually identified as yellowtail (*S. quinqueradiata*), amberjack (*S. dumerili*) and goldstriped amberjack (*S. lalandi*). However, the term yellowtail is often used in a generic sense for *Seriola* spp. Therefore, to prevent confusion (and with great respect to the Japanese authors), wherever possible the "FAO" English names have been used where specific types of yellowtail are being referred to in the chapter, namely the Japanese amberjack (*S. quinqueradiata*), the greater amberjack (*Seriola dumerili*), and the yellowtail amberjack (*S. lalandi*). Several Japanese terms for yellowtail are also frequently used in this chapter. These include "*mojako*" (Japanese amberjack <50 g), "*hamachi*" (Japanese amberjack <5 kg), "*buri*" (Japanese amberjack >5 kg), "*kampachi*" (greater amberjack), and "*hiramasa*" (yellowtail amberjack).

The greater amberjack, *S. dumerili*, is a cosmopolitan species, found in warm waters all over the world. Its main morphological characteristics are the elongated, fusiform and slightly laterally compressed body, covered with small scales (cycloids). Their colour is yellow-green in juveniles; in adults it is blue or olivaceous dorsally and silvery to white on the sides and belly. *S. dumerili* is a multiple spawning fish, and it may release several batches of eggs during the same spawning season. The ovary type in this group is synchronous: at least two size groups of oocytes are present at the same time (Grau 1992). This species is gonochoric without sexual dimorphism, and both sexes are separated. According to Micale *et al.* (1993), maturity occurs at three years of age but functional breeders are 4 and 5 years old for males and females respectively. Marino *et al.* (1995) reported the first reproductive season for this species to be at 4 years of age for both sexes, even though 40% of males are sexually mature at 3 years of age.

Japanese amberjack (*S. quinqueradiata*) are present in the Western Central Pacific Ocean from Japan and the eastern Korean Peninsula to the Hawaiian Islands. This species reaches a maximum size of 150 cm TL (male/unsexed) and a maximum weight of 40 kg. It shows asynchronous oocyte development.

Yellowtail amberjack (*Seriola lalandi*) are present in Atlantic, Pacific and Western Indian Oceans. It is considered a circumglobal species, supporting commercial and recreational fisheries worldwide. This species is a spring-summer spawner, with a multiple group synchronous oocyte development and, like the greater amberjack (*S. dumerili*), has the capacity for multiple spawning within a reproductive season. The smallest size at which females caught in New Zealand matured was 775 mm FL; 50% reached sexual maturity at 944 mm, while all were mature at 1 275 mm (Poortenaar, Hooker and Sharp 2001); McGregor (1995) reported maturity at 580-670 mm. In Australia, according to Gillanders, Ferrel and Andrew (1999a,b), mature females of this species appeared at 698 mm (3 years) reaching 50% at 834 mm (4-5 years). The differences in size between these 2 populations could be attributed to different rearing conditions.

Tables 55-57 summarize the characteristics of these species, while Figures 102-107 illustrate their appearance and geographical location.

Seriola dumerili (Risso, 1810)

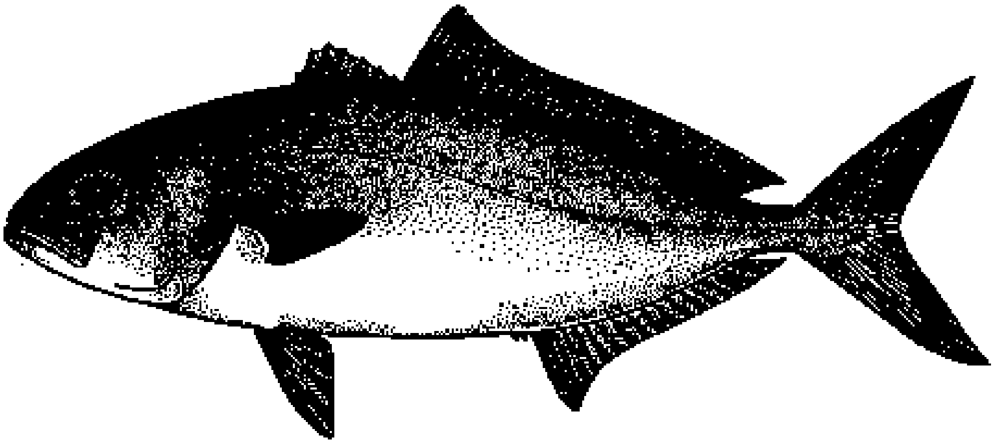


Figure 102. Greater amberjack *(Seriola dumerili)* (FAO)

Table 55. Characteristics of the greater amberjack *(Seriola dumerili)* (FishBase 2002, modified)

Common name	Greater amberjack.
Size and age	Maximum reported size 180-190 cm TL and maximum weight 80.6 kg, but commonly are 110 cm and 25-40 kg (Paxton *et al.* 1989; Smith-Vaniz 1986).
Environment	Marine, reef-associated. 1-360 m depth.
Climate and latitude	Lives in a subtropical climate at 45°N-28°S (Paxton *et al.* 1989) and is both epibenthic and epipelagic (Smith-Vaniz 1986).
Resilience	Minimum population doubling time about 1.4-4.4 years, with medium resilience.
Distribution	Circumglobal. Indo-West Pacific: South Africa, Persian Gulf, southern Japan and the Hawaiian Islands, south to New Caledonia, Mariana and Caroline Islands, in Micronesia; West Atlantic, Bermuda, from Mediterranean to the Gulf of Biscay and rarely off the British Coast; Nova Scotia (Canada) to Brazil, also from the Gulf of Mexico and the Caribbean Sea (Cervigón 1992).
Biology and ecology	Marino *et al.* (1995) reported the first reproductive season for this species to be at 4 years of age for both sexes. The spawning season lasts from late spring to early summer (from May to July) (Lazzari and Barbera 1988, 1989a; Grau 1992) in the Mediterranean. Feeds primarily on fish but also invertebrates (Smith-Vaniz 1986). Small juveniles are associated with floating plants in oceanic and offshore waters and form small schools or may be solitary.
Importance	This species is very important for fisheries and aquaculture (Frimodt 1995).

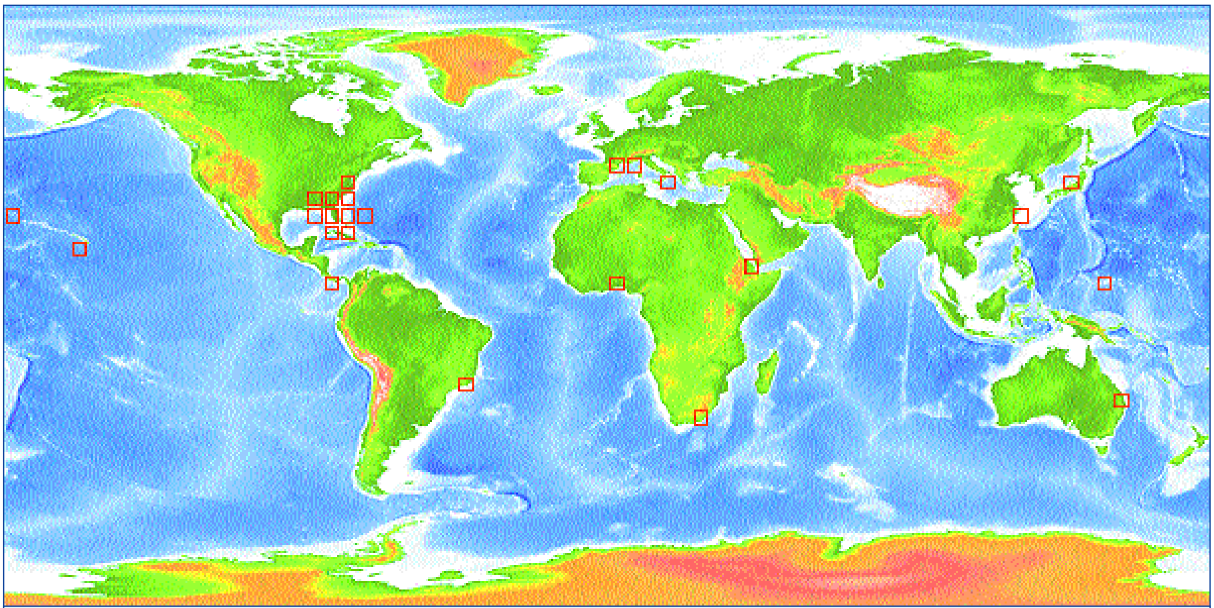


Figure 103. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Seriola dumerili* (FishBase 2002)

Seriola quinqueradiata (Temminck and Schlegel, 1845)

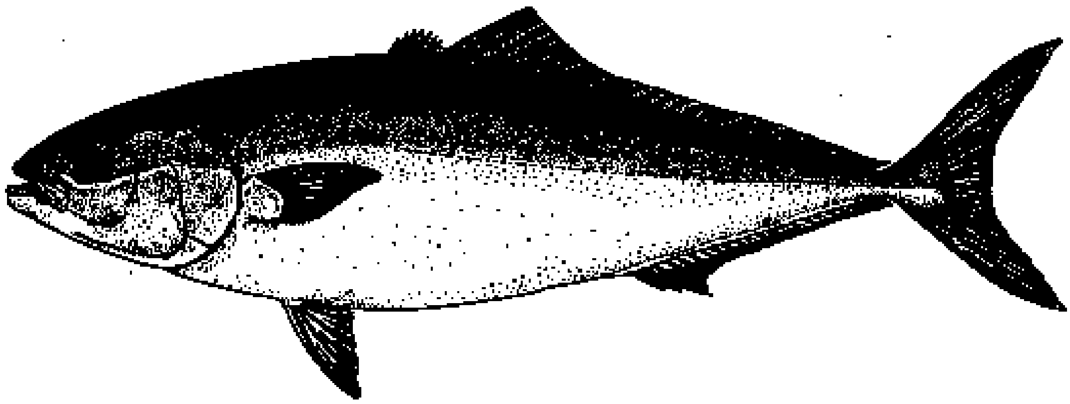


Figure 104. Japanese amberjack or yellowtail *(Seriola quinqueradiata)* (FAO)

Table 56. Characteristics of the Japanese amberjack or yellowtail *(Seriola quinqueradiata)* (FishBase 2002, modified)

Common name	Japanese amberjack or yellowtail.
Size and age	Maximum size of 150 cm TL (male/unsexed) and maximum weight 40 kg.
Environment	Marine demersal species that lives at 100 m depth (Robins *et al.* 1991).
Climate and latitude	Subtropical climate (32°N-20°N).

Resilience	Minimum population doubling time is less than 15 months, with high resilience.
Distribution	Present in the North West Pacific Ocean from Japan and the eastern Korean Peninsula.
Biology and ecology	This species spawns about February-March. However, when held in captivity it begins maturing and spawning two months later in late April to early May (Mushiake 1997). The species exhibits shoaling habit (Frimodt 1995). Juveniles are found among floating seaweeds (Safran 1990).
Importance	High commercial importance in fisheries and in aquaculture, in particular in Japan where the young are collected, raised in captivity and marketed fresh for "*sashimi*" (Frimodt 1995).

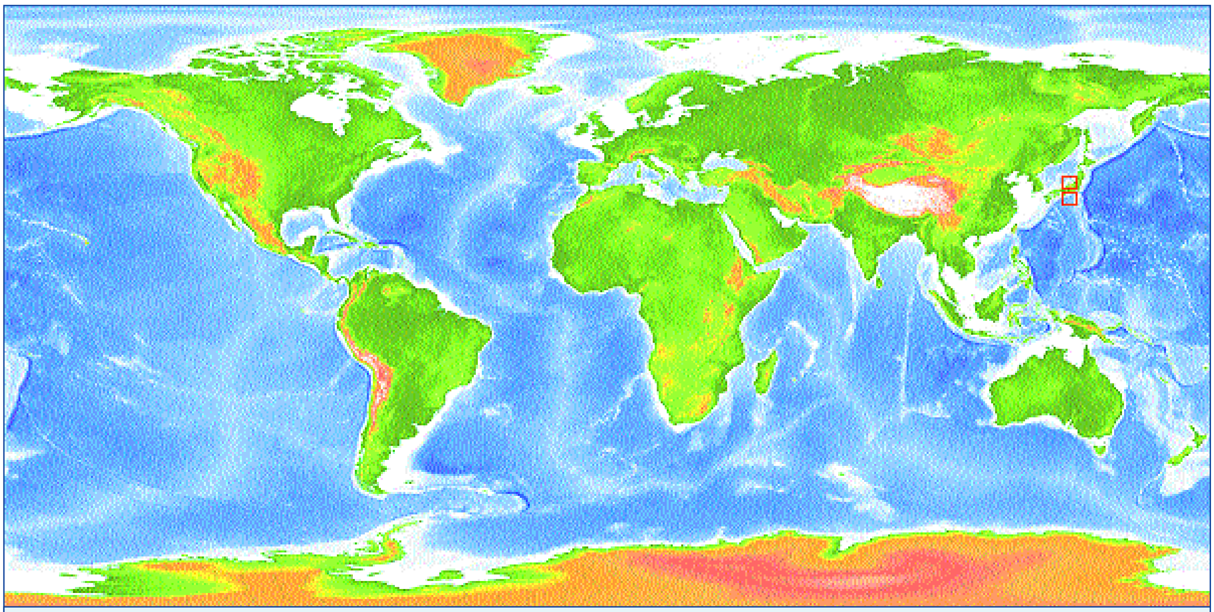


Figure 105. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Seriola quinqueradiata* (FishBase 2002)

Seriola lalandi (Valenciennes, 1833)

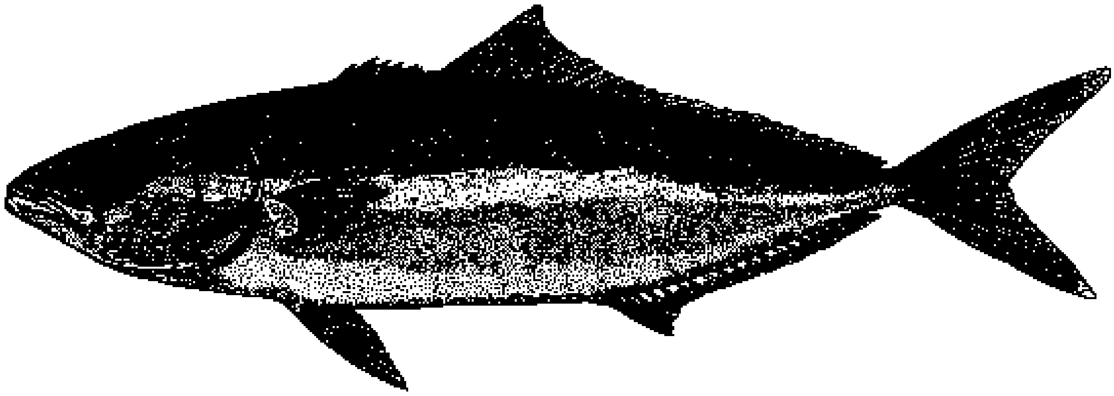


Figure 106. Yellowtail amberjack or goldstriped amberjack *(Seriola lalandi)* (FAO)

Table 57. Characteristics of the yellowtail amberjack or goldstriped amberjack *(Seriola lalandi)* (FishBase 2002, modified)

Common name	Yellowtail amberjack or goldstriped amberjack.
Size and age	Maximum length 250 cm TL (male/unsexed) and maximum weight about 97 kg.
Environment	Pelagic and demersal. Brackish and marine waters, 50 m depth, with a temperature range of 18-24°C (Paxton *et al.* 1989).
Climate and latitude	Subtropical (54°N - 43°S).
Resilience	The minimum population doubling time is less than 15 months with an high resilience.
Distribution	Circumtropical, entering into temperate waters in some areas. Indo-Pacific: Japan, Great Australian Bight and Southeast Australia. Reported from Walters Shoal (Fricke 1999). In the Eastern Pacific it is found in British Columbia, Canada to Chile (Eschmeyer, Herald and Hammann 1983); Eastern Atlantic: St. Helena, South Africa (Smith-Vaniz, Quéro and Desoutter 1990).
Biology and ecology	Lives in coastal and oceanic waters and is both pelagic and demersal (Smith-Vaniz 1995), sometimes entering estuaries (May and Maxwell 1986). Can sometimes be found in cooler waters. Can be solitary or found in small groups near rocky shores, reefs and islands and off kelp beds (Eschmeyer, Herald and Hammann 1983). Juveniles are present in offshore waters as schools, very often near or beyond the continental shelf (Smith 1987). Feeds on small fish, squid and crustaceans (Bianchi *et al.* 1993).
Importance	This species is important for fisheries and aquaculture and in the market is sold fresh and salted/dried (Smith-Vaniz 1995).

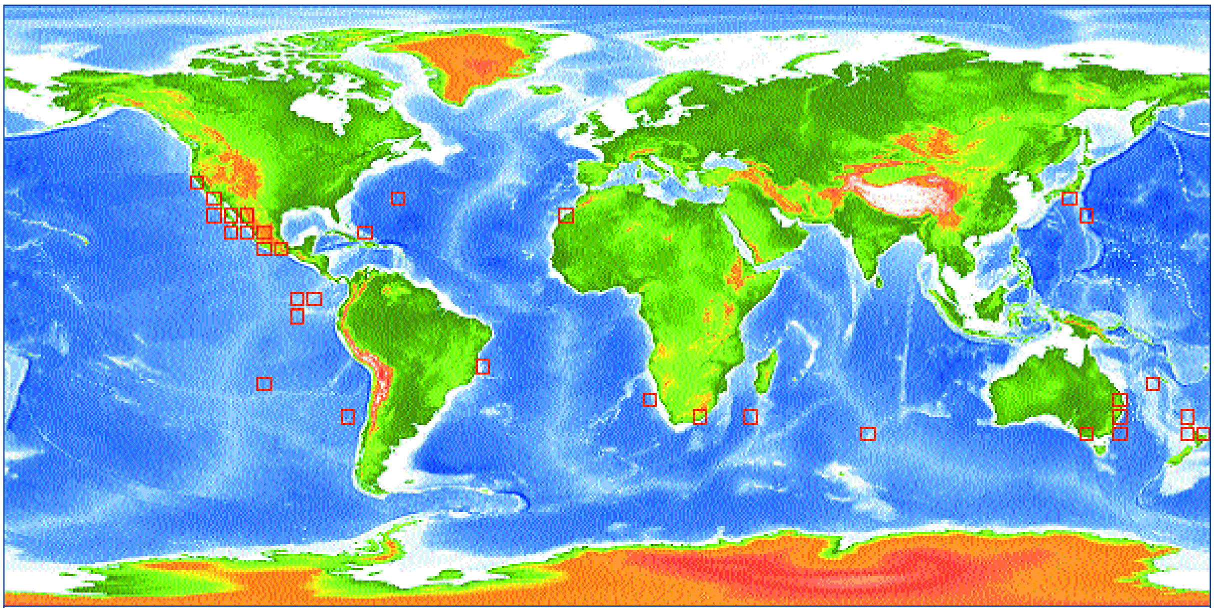


Figure 107. Zoological sites sampled for geographic distribution (indicated by the red squares) of *Seriola lalandi* (FishBase 2002)

Fishery trends

Yellowtail are captured all over the world, due to their market demand (e.g. in Italy their average price is € 20/kg). The three species considered in this report are captured both for direct consumption and for aquaculture (on-growing) purposes. FAO data for the global fisheries catch of yellowtail refers to *S. dumerili*, *S. quinqueradiata*, *S. lalandi* and *Seriola* spp.; most is not species specific. In total the catch shows a fluctuating but expanding trend which peaked in 2000 with 100 456 tonnes (Figure 108).

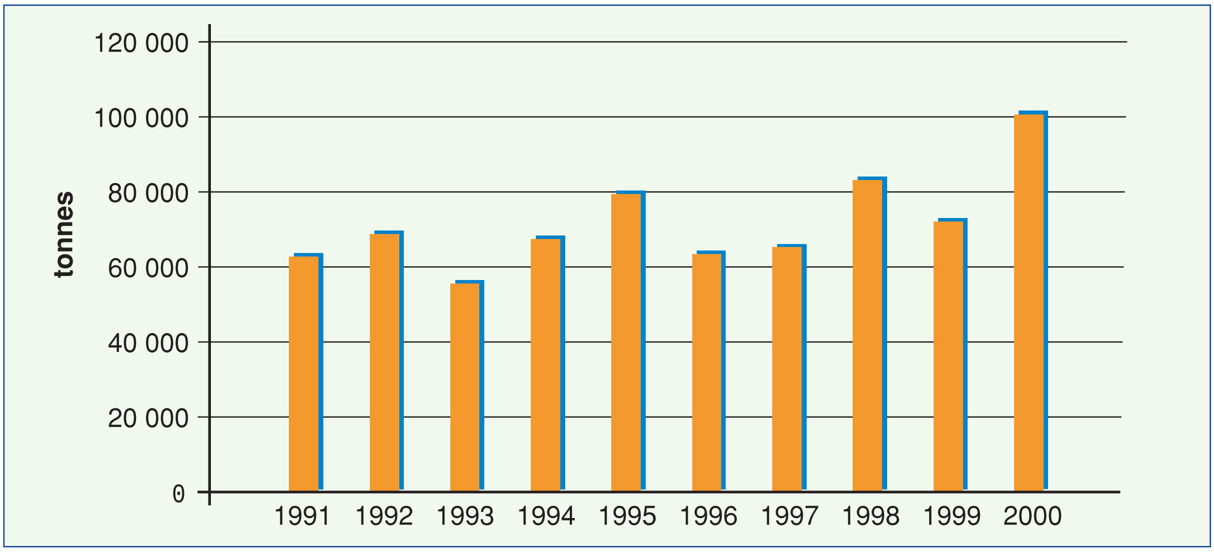


Figure 108. Global trends in yellowtail catch, 1991-2000 (FAO 2002b)

In 2000, most of the catch of yellowtail was made in Asia, which accounted for 80% of the total landings, followed by South America (12%) and North America (3%). The major fishing area in that year was the North-western Pacific, followed by South-eastern Pacific (Figure 109). The major countries that caught yellowtail in 2000 were Japan, followed by Peru and the Republic of Korea (Figure 110).

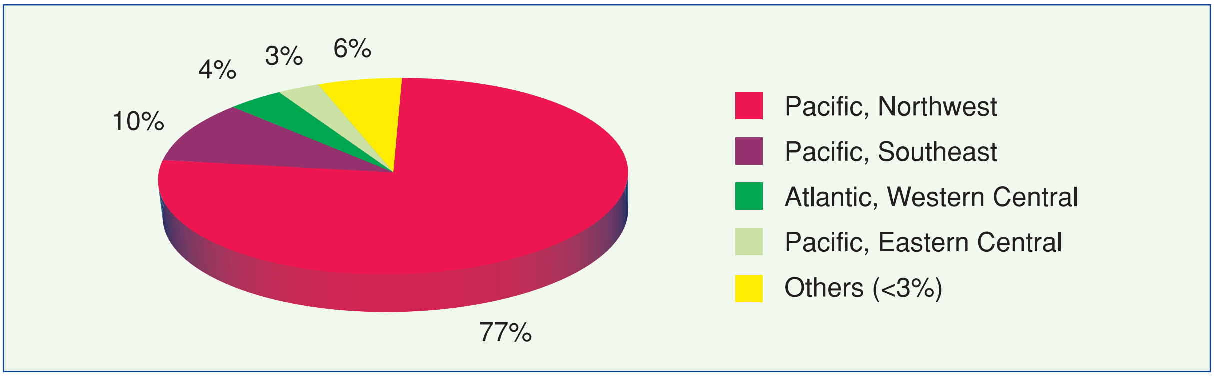


Figure 109. Catch of yellowtails by area in 2000 (FAO 2002b)

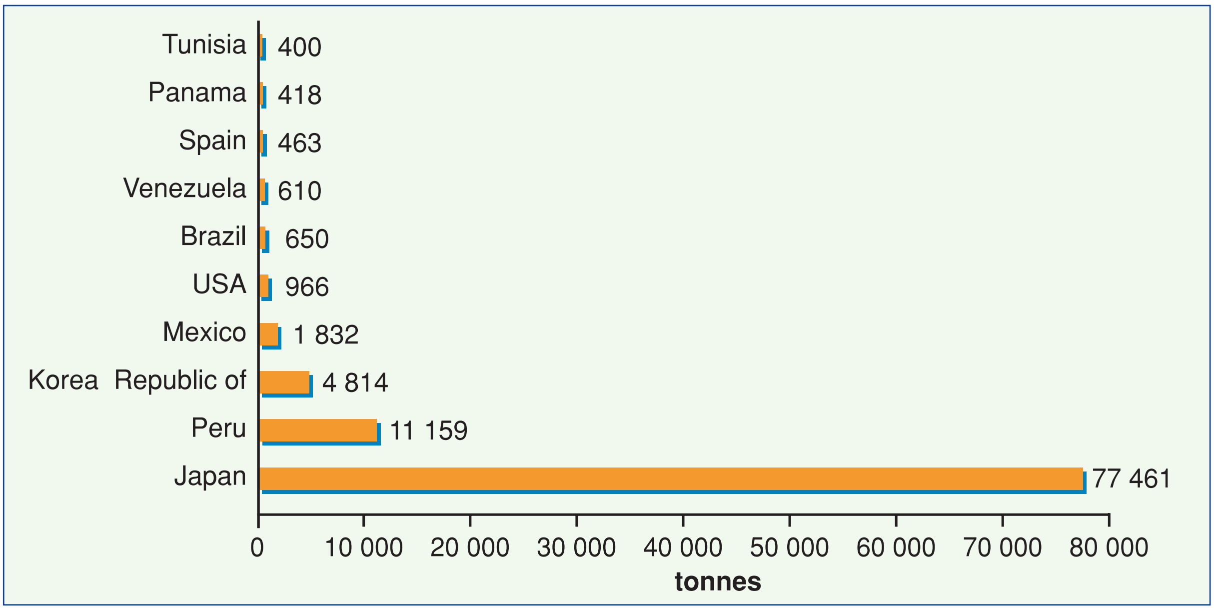


Figure 110. Global catch of yellowtails: top ten countries in 2000 (FAO 2002b)

While Figures 108-110 summarized the global catch for all yellowtail, more detailed information is provided in Figures 111-117. The fishery catch of greater amberjack (*S. dumerili*) has increased significantly over the last ten years, from 336 tonnes in 1991 to 2 004 tonnes in 2000 (Figure 111). In 2000, the majority (72%) of greater amberjack were caught in the Mediterranean and the Black Sea area (1 445 tonnes) (Figure 112). The catch by country is shown in Figure 113; the USA, Tunisia, Spain and Israel all caught more than 300 tonnes in 2000.

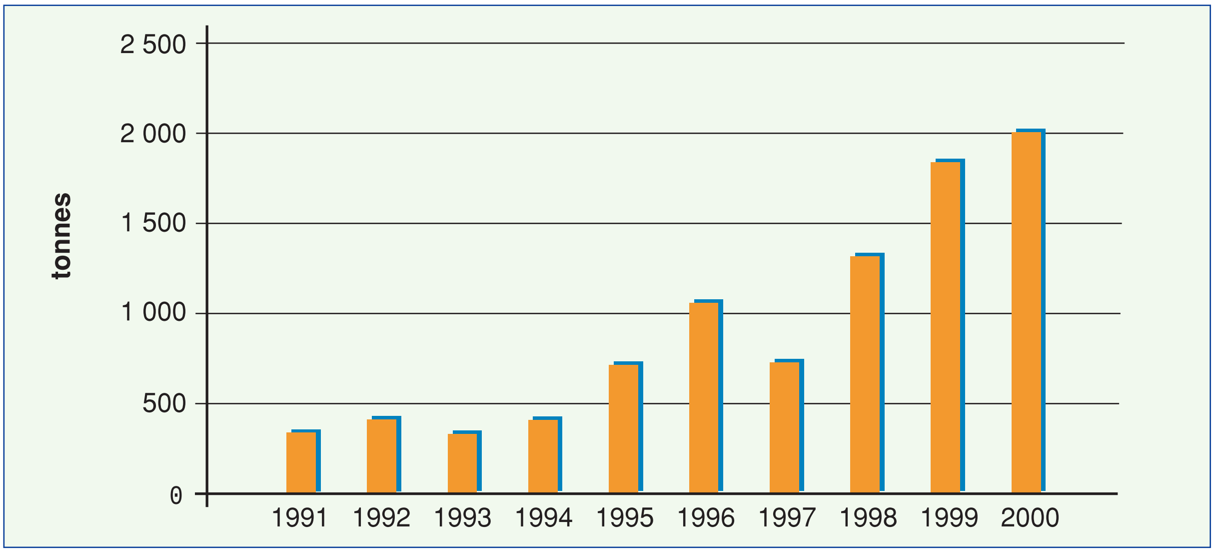


Figure 111. Trends in the global catch of greater amberjacks *(Seriola dumerili)* 1991-2000 (FAO 2002b)

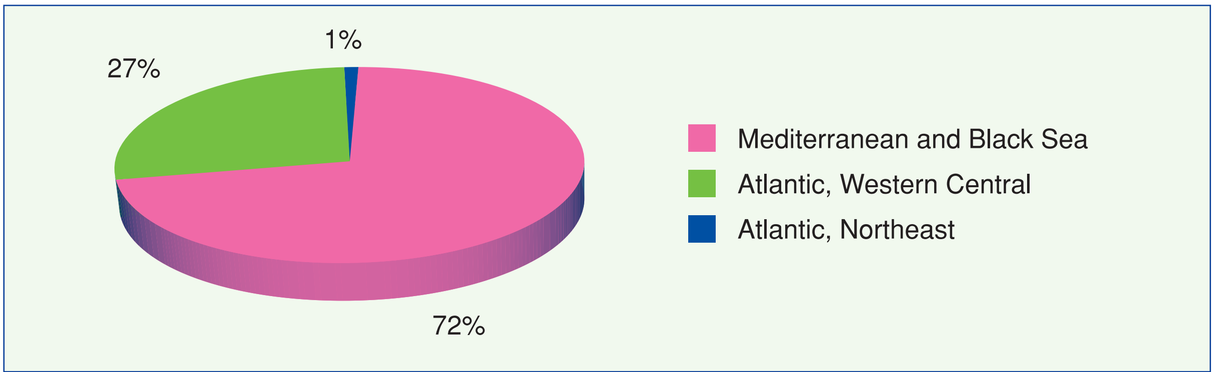


Figure 112. Global catch of greater amberjacks *(Seriola dumerili)* by area in 2000 (FAO 2002b)

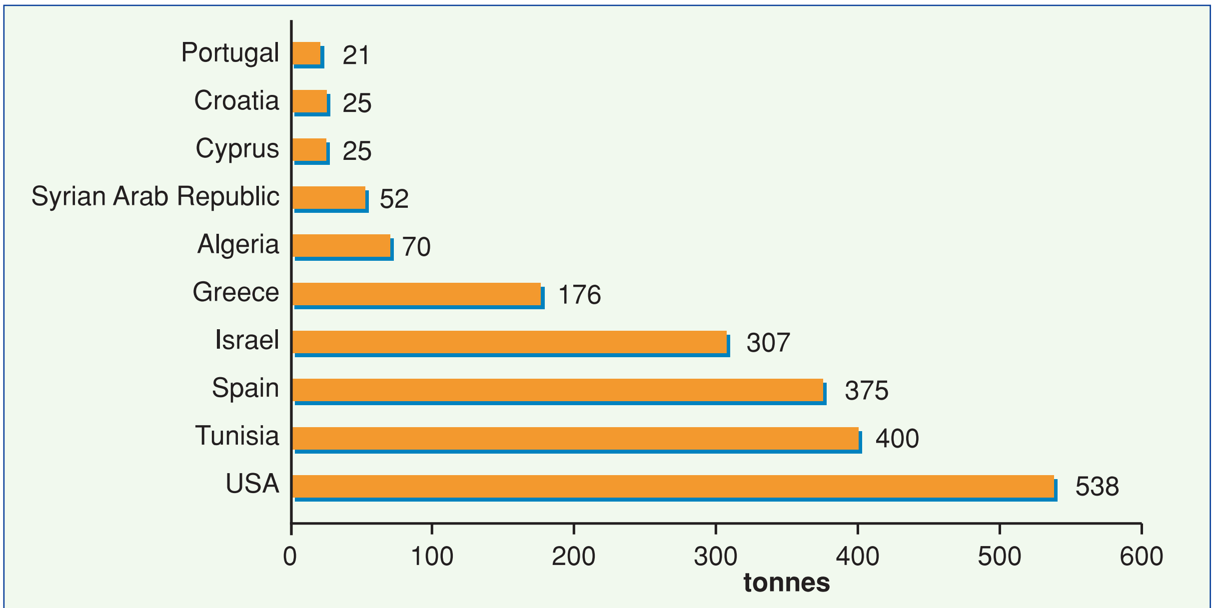


Figure 113. Catch of greater amberjacks *(Seriola dumerili)* by country in 2000 (FAO 2002b)

FAO (2002b) only records a specific catch of the Japanese amberjack (*S. quinqueradiata*) during this decade for the years 1995 and 1996. Most data for these and other years is "hidden" in the general category *Seriola* spp. However, it has been possible to construct Figure 114 from data provided by M. Nakada (pers. comm. 2002); this shows that the catch rose to a peak in 1995, followed by a decline. This species is still caught in Japan as small yellowtails called "*buri*" (50 to 60 cm in body length). These are caught in set nets and are strong competitors of cultured yellowtails in the market (Nakada 2000).

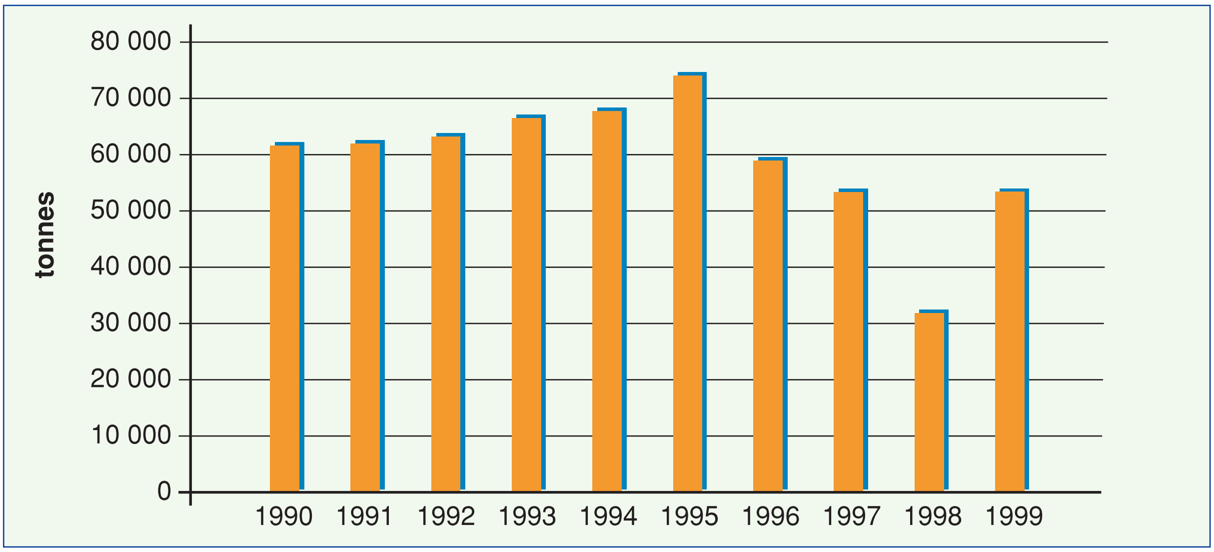


Figure 114. Catch of Japanese amberjacks *(S. quinqueradiata)* by Japan, 1990-1999
(M. Nakada, pers. comm. 2002)

The catch of the yellowtail amberjack (*S. lalandi*) is irregular (Figure 115) and insignificant in the overall global yellowtail market. In 2000 the major fishing area for this species was South-western Atlantic, which yielded 63% of the global catch (Figure 116). The principle fishing nation for this species in 2000 was Brazil (Figure 117).

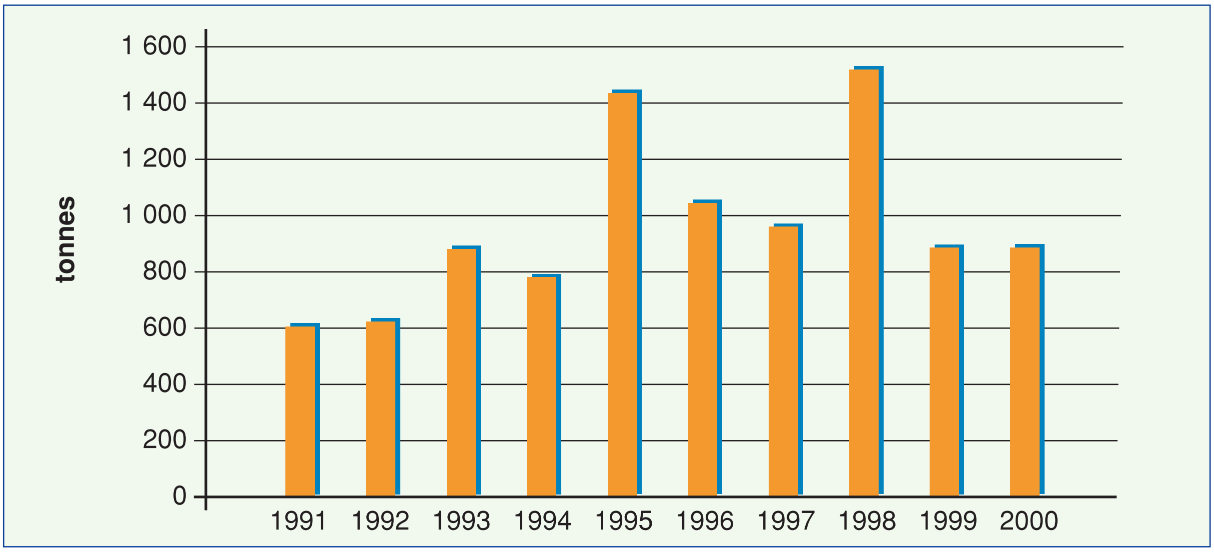


Figure 115. Trends in the global catch of yellowtail amberjacks *(Seriola lalandi)* 1991-2000
(FAO 2002b)

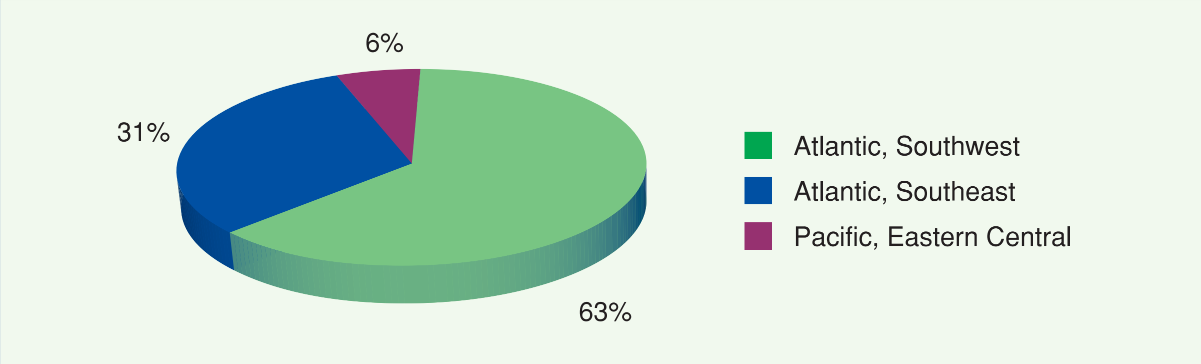


Figure 116. Catch of yellowtail amberjacks *(Seriola lalandi)* by area in 2000 (FAO 2002b)

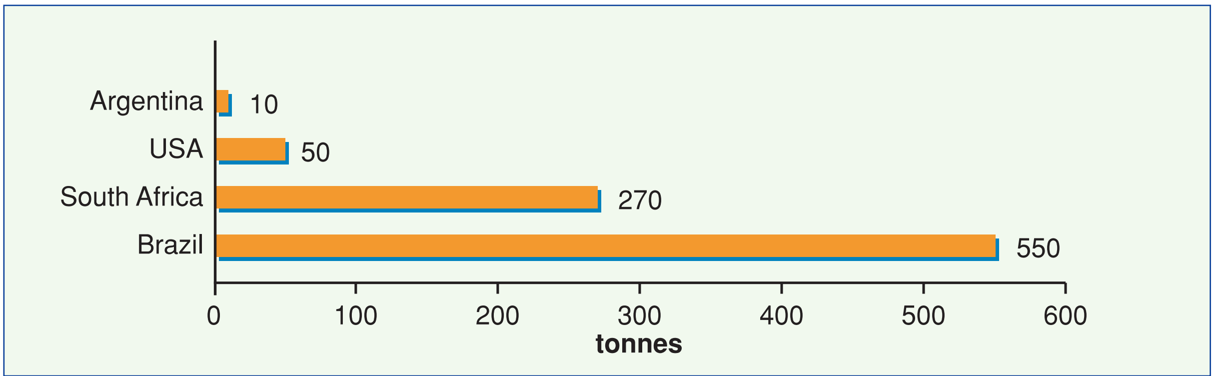


Figure 117. Catch of yellowtail amberjacks *(Seriola lalandi)* by country in 2000 (FAO 2002b)

Availability of "seed" for capture-based aquaculture

Yellowtail aquaculture is still based, both in Asian countries and Mediterranean, on the availability of capture-based "seed". This is the bottleneck for the capture-based aquaculture of *Seriola* spp., especially in Mediterranean countries, where the greater amberjack (*S. dumerili*) does not spawn in captivity. In Asian countries, mainly in Japan, artificial production of *Seriola* spp. "seed" has been achieved, but not at a commercial scale for sea-ranching and restocking goals. This section of this report reviews the global trend and availability of yellowtail, their main catching areas and the management of the catches, e.g. in Japan for "*mojako*" (defined in the introduction to this chapter) of the Japanese amberjack (*S. quinqueradiata*), to prevent overfishing of the resource.

In Japan, *S. dumerili* has been reared from hatching to the juvenile stage (Masuma, Kanematu and Teruya 1990; Tachihara, Ebisu and Tukashima 1993); however, since 1988, most of the "seed" (8 to 10 cm size) has been imported from other Asian countries, mainly via Hong Kong from China and Taiwan Province of China (Wakabayashi 1996).

The natural spawning grounds of the adults of the Japanese amberjack (*S. quinqueradiata*), farmed mainly in Japan and in Korea, are in the East Chinese Sea, between Taiwan Province of China and Japan. The fish spawn in the warm waters of the Kuroshio current (18-20°C) as it moves northwards. Consequently, spawning begins north of Taiwan Province of China in the spring and finishes in the early summer off the southern islands of Kyushu and Shikoku (Kimura, Kasai and Sugimoto 1994; Nash 1995; Kasai *et al.* 1998). The emergent larvae (about 3.5 mm) attach themselves to seaweeds drifting in the current. At first, they swim freely in the current as fingerlings up to 15 cm in length; afterwards they migrate in large numbers to the coastal waters of southern Japan and the Korean Peninsula.

From season to season, various sizes of Japanese amberjack can be caught in different parts of Japan; therefore, special names are given to them in the different regions. For the Japanese, Japanese amberjack are ascending fish ("*shusse-uo*"), meaning that their name changes according to its size. To make it even more confusing, these names also vary on a regional basis. In the Kanto region of Japan (around Tokyo) the 2.5-5 cm long fry are called "*mojako*". Fingerling Japanese amberjack up to the length of 15 cm are called "*wakashi*". When they grow larger, up to 40 cm, they are known as "*inada*". From 40 cm to 65 cm they are called "*warasa*" (mainly in Tokyo). Adult Japanese amberjack are called "*buri*" throughout Japan. Recently, the domestic supply of "*mojako*" showed a significant decrease (Figure 118), and several million have once again been imported from Korea (e.g. 8 million in the 1980s) and Viet Nam (e.g. 450 000 yellowtail fry were exported to Japan by Viet Nam in 1995).

In 1966, the Japanese Fisheries Agency imposed regulations limiting the number of "*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 prefectural 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. In 1977, the number of "*mojako*" actually caught was about 45 million. The number has fluctuated wildly between 30 and 50 million for about 20 years but fell as low as 25 million in 1997 and 1999 (Table 58).

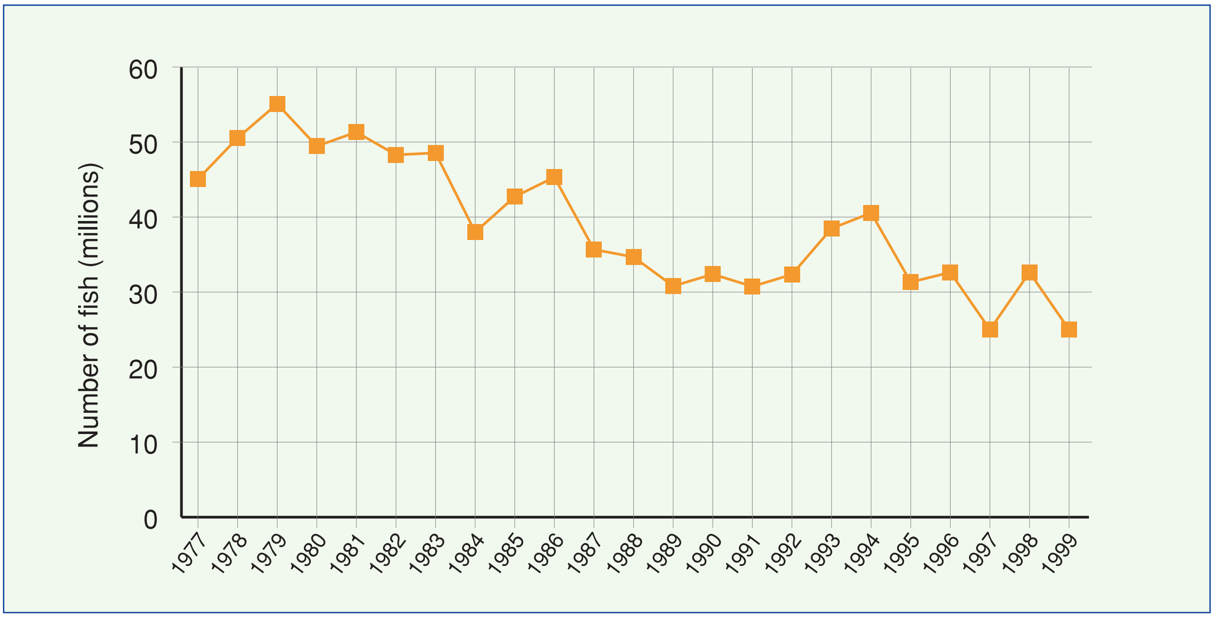


Figure 118. Fluctuation in the number of available "*mojako*" (Nakada 2000, modified)

Table 58. Number of "*mojako*" caught in each Japanese Prefecture (Source: Japan Seawater Fisheries Culture Association)

Prefecture	1996	1997	1998	1999	2000	2001
	Numbers of fish ('000)					
Shizuoka	497	374	174	272	303	191
Ishikawa	0	0	0	20	0	0
Fukui	58	27	7	0	0	7
Mie	949	578	605	840	912	609
Kyoto	0	0	0	0	0	1
Wakayama	678	443	385	351	495	818
Hyogo	180	132	65	134	147	137
Tottori	142	81	50	130	130	130
Shimane	401	84	255	347	363	229
Yamaguchi	331	241	218	162	274	328
Tokushima	134	1 135	1 040	1 417	1 479	1 077
Kagawa	550	115	438	232	231	11
Ehime	10 455	7 480	7 286	6 146	9 566	7 446
Kochi	3 285	1 896	1 969	2 193	2 782	2 045
Fukuoka	30	26	16	11	10	15
Nagasaki	3 888	3 241	3 215	3 246	3 262	3 170
Kumamoto	1 511	1 012	879	1 000	1 007	793
Oita	2 658	1 724	2 175	1 675	2 215	1 947
Miyazaki	863	794	854	396	1 277	1 085
Kagoshima	5 893	5 512	4 901	4 869	6 092	4 584
Others	132	101	169	53	394	74
Total	**32 635**	**24 996**	**24 701**	**23 494**	**30 939**	**24 697**

Yellowtail amberjack (*S. lalandi*; also known as yellowtail kingfish in Australia and goldstriped yellowtail in Japan,) are cultured commercially in South Australia and Japan, and experimentally in New Zealand. In Japan, this species is especially popular in the northern Kyushu area. In 1997, 2.5 million large juvenile yellowtail amberjack ("*hiramasa*"), were caught in the waters around the Goto Islands and cultured. The total annual catch of yellowtail amberjack is less than either Japanese amberjack or greater amberjack (Nakada 2000).

In the Mediterranean region (e.g. Spain), some experimental work has been undertaken. The production of greater amberjack *S. dumerili* is mainly based on raising fingerlings, captured from the wild at the end of the summer. The poor availability of wild juveniles and the high cost of catching them constitute a bottleneck to the commercial rearing of this species (Porrello *et al.* 1993). In general, the fishery area follows the geographical distribution of the species, with the greater catches being taken during the spawning season. The spawning season of *S. dumerili* is protracted and lasts from late spring to early summer (from May to July) (Lazzari and Barbera 1988, 1989a; Grau 1992) in the Mediterranean. Grau *et al.* (1996) found that the spawning season in the Balearic Islands occurs earlier than previously reported for the same species in other Mediterranean areas (Lazzari and Barbera 1988, 1989a). Lazzari and Barbera (1988, 1989b) and Andaloro, Potoschi and Porrello (1992) found that the main spawning site for the greater amberjack in the Mediterranean region is located in the Central Mediterranean Sea, off the Pelagie Islands.

The fishery for greater amberjack juveniles for aquaculture purposes is made in "nursery" areas located in Southern Adriatic (Benovic 1980), in Southern Sicily (Giovanardi *et al.* 1984; Lazzari and Barbera 1989a), in Eastern Sicily and in the Aeolian Archipelago (Greco *et al.* 1991, 1992; Porrello *et al.* 1993). Other recruitment areas were identified in the South Thyrrenian Sea by Caridi *et al.* (1992) and the juvenile availability was assessed by Andaloro (1993). For Italian fisheries, this species is considered an under exploited resource (Andaloro, Potoschi and Porrello 1992); the frequency of captures, the only available data for assessing biomass, shows a little change (Andaloro 1993). Catches of about 2 million juveniles/year (<200 g total body weight) were recorded on the northern and eastern coasts of Sicily, although most of them were caught by sport fishermen, and rarely for aquaculture purposes (Marino *et al.* 1995).

Catching methods for capture-based aquaculture

Young greater amberjack (25-100 g) are captured from the end of August to the beginning of October-December in the Mediterranean (Andaloro, Potoschi and Porrello 1992; Lazzari and Barbera 1989a,b; Potoschi *et al.* 1999) by using fish aggregating devices (FADs) made from leaves and branches called "*ramos*" or "*catcés*", to which they are attracted (Grau 1992; Greco *et al.* 1991). Flotsam and FADs are used by fishermen to improve pelagic and demersal fish catches, mainly in the central and western Mediterranean basin (Massutì and Morales-Nin 1991, 1995). Oceanic and coastal FADs minimize both searching time and operating costs for fishing vessels. While the traditional FADs in Mediterranean have undergone little modification, both their design and durability has been improved in the United States (Raymond, Itano and Buckley 1989).

In Sicily, traditional FADs are built with vegetal material and their use is linked exclusively to the availability of economically important species, e.g. greater amberjack (Potoschi and Sturiale 1996). Before reaching the FAD area, juveniles aggregate under floating objects such as flotsam and vegetal matter. These objects have been seen to play an important role in the diffusion and transport of young fish towards coastal areas (Druce and Kingsford 1995). A typical example of the capture of greater amberjack juveniles is seen in the Castellammare Gulf (Sicily region, Italy): from July to December, several hundred FADs, built with palm leaves (covering approximately 2 m^2), or with green canes (covering 4-5 m^2) (Mazzola *et al.* 1993; D'Anna, Badalamenti and Raggio 1999; Piscitelli *et al.* 2001). These are positioned to float in the Gulf, and are anchored with a rope to a ballast weighing 30-40 kg. They are set along transects extending perpendicularly to the coast for several kilometres. The transects extend from shallow (<15 m) coastal waters offshore to depths of about 500 m. The same method is used in several other areas of Sicily for catching wild juveniles for rearing in open sea cages (Badalamenti *et al.* 1998). Near these FADs, named "*cannizzu*" (pronounced "ca-nni-tzu"), fishermen use simple purse seines for catching greater amberjack juveniles. When these hover underneath FADs, they gain a number of advantages. For example, they are able to save energy because the floating structures are anchored to the sea bottom and there is thus no need for the fish to swim, but only to hover, in order to catch prey. Furthermore, staying in the shade means that predators cannot see the juveniles while the juveniles themselves can spot their prey more easily. Their twilight feeding activity also facilitates prey location (Badalamenti *et al.* 1995, 1998).

Juveniles are captured in the Aeolian Islands under drifting flotsam and, to improve catch rates, artificial wreckage made up of twisted cane mats, moored to the bottom are used; small manual purse seines (20 mm mesh) are made specifically for catching greater amberjack by these FADs (Porrello *et al.* 1993). Wild juveniles (30-50 g or 80-100 g) are caught with a purse seine net set around FADs in Spain, during August to October. These are then reared in floating cages, reaching about 1 kg by the following June (Crespo *et al.* 1994; Nash 1995). However, production of farmed greater amberjack at a commercial level in Spain stopped in 1999, but it is still cultured on a limited scale in seabass/seabream farms there, to test its feasibility and market potential.

Greater amberjack are also an important fish in aquaculture in Taiwan Province of China. There, juveniles again aggregate under FADs and are caught by a small seine net for environmental survey purposes (Liu 1985, 2001).

The techniques used for capturing Japanese amberjack (*S. quinqueradiata*) are similar to those employed for *S. dumerili* and *S. lalandi*. "*Mojako*" of 2-10 g are caught under drifting Sargasso seaweed with a circular net from fishing boats, round haul-nets or hand-nets from April to June, and then transported to collection sites. The total catch is higher along the Pacific coast than in the Sea of Japan. The smallest size of fish associating with FADs in Japanese amberjack is 12 mm TL; at this length, they show mutual attraction and soon form shoals around flotsam or other floating objects (Hong Seong *et al.* 1997; Masuda and Tsukamoto 1999).

Transfer of juveniles from fishing to on-growing facilities

The practice in Italy is to catch greater amberjack juveniles and to transfer them within PVC tanks placed on board fishing vessels with open water re-circulation and oxygenation systems, and sometimes with temperature regulators (Greco *et al.* 1991, 1992; Caridi *et al.* 1992). The optimum density for juvenile transport has been calculated to be 2 kg/m^3 (Caridi *et al.* 1992). In some cases mortality from handling stress has been reported, ranging from 1.5% to 2% (Greco *et al.* 1991; Porrello *et al.* 1993) and 5-6% (Lazzari and Barbera 1989a). The capture and transportation of *S. dumerili* juveniles to cages in general (Mazzola, Mirto and Danovaro 2000) caused negligible mortalities, proof of the species "hardiness".

In Japan, wild juveniles are weaned onto prepared feed after capture, and weak individuals are removed. They are then sold to producers who put them into net cages. Small juvenile Japanese amberjack and related species are sensitive to feed deprivation. If a fishing boat catches "*mojako*" far away from port the fish will become cannibalistic in the holding tanks. Yellowtail fry (25-40 mm in length) are kept in onboard storage tanks until return to port. If the fish do not receive feed for more than three days, the "*mojako*" fail to adapt to the prepared feed. It has been shown that a prolonged fasting period, before first feeding in net pens, will significantly affect growth rates later in the culture period. If a good quality prepared feed is accepted while the fish are on the collecting boat, the problem can be overcome (Nakada 2000).

Trends in aquaculture production

The global production of yellowtail reported by FAO (FAO 2002a) includes several species but mostly consists of Japanese amberjack (*Seriola quinqueradiata*). The total farmed production shows a decrease from 162 001 tonnes in 1991 to 137 961 tonnes in 2000 (Figure 119). Nearly all of the global production is by mariculture systems in Asia, predominately in Japan. The Republic of Korea and Taiwan Province of China (the latter, both in marine and brackish waters) are also listed as producers.

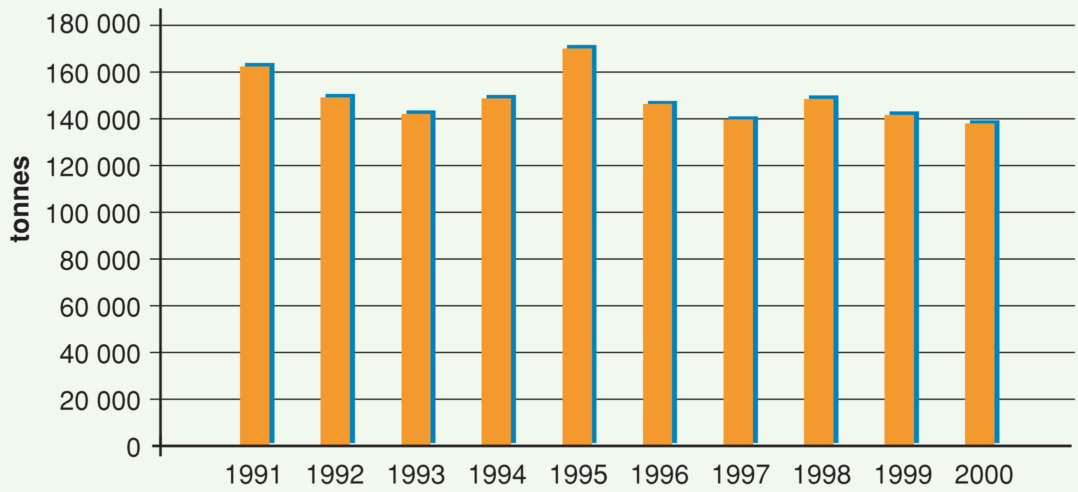


Figure 119. Global production of yellowtails through aquaculture, 1991-2000 (FAO 2002a)

Japanese amberjack have been farmed in Japan since 1927, when young yellowtail caught in large set nets were released into embankment-type enclosures in AdoIke (Kagawa Prefecture). Significant production did not occur until the 1950s, with the replacement of farming in tidal enclosures by organized offshore cage culture, which resulted in a better quality product. Fry are cultured from 4-5 g and farmers have been able to maintain annual production of around 140 000 tonnes until 2000 (Table 59). Japan accounted for 99% of the global production of Japanese amberjack in 2000 (FAO 2002a); the only other producers were Taiwan Province of China (633 tonnes) and the Republic of Korea (494 tonnes). There were 3 991 farms in 1977 but the numbers decreased until, by 2000, there were only 1 279 (Table 59). Despite this, total production has changed little, which indicates some consolidation in the industry, with some smaller producers being incorporated into larger farms (M. Mahita, pers. comm. 2002; Nakada 2000). Table 60 shows that by far the highest farmed production is from the Kagoshima Prefecture.

Table 59. Trends in the total farmed production of yellowtails compared to the number of fish farms in Japan (M. Mahita, pers. comm. 2002)

Year	Total Production (tonnes)	Fish farms (No.)	Average production (tonnes/farm)
1994	148 181	2 082	71
1995	169 765	1 974	86
1996	145 773	1 457	100
1997	138 234	1 392	99
1998	146 849	1 290	114
1999	140 441	1 294	108
2000	136 200	1 279	106

Table 60. Trends in cultured Japanese amberjack production (tonnes) (Source: Statistics and Information Department, Ministry of Agriculture, Forestry and Fisheries, Japan)

Prefecture	1996	1997	1998	1999	2000
Shizuoka	1 403	842	730	713	500
Ishikawa	32	32	32	32	0
Fukui	34	31	24	1	-
Mie	2 747	1 872	1 791	1 737	1 500
Kyoto	1 032	281	206	222	100
Wakayama	2 050	1 420	1 142	1 149	900
Hyogo	322	329	588	709	600
Tottori	400	323	538	472	100
Shimane	2 270	432	1 233	211	900
Yamaguchi	658	601	495	488	500
Tokushima	2 474	2 429	3 273	2 381	2 500
Kagawa	13 433	11 479	10 205	11 189	10 800
Ehime	28 996	27 385	28 400	23 298	24 100
Kochi	9 586	9 971	10 473	10 398	10 100
Fukuoka	2	1	3	5	-
Nagasaki	15 934	12 762	13 857	12 405	11 400
Kumamoto	6 420	6 406	6 450	6 730	5 700
Oita	10 720	13 983	13 519	12 063	11 900
Miyazaki	6 238	7 609	9 221	10 073	9 800
Kagoshima	39 331	38 812	43 149	44 534	43 100
Others	1 691	1 434	1 520	1 601	1 700
Total	**145 773**	**138 434**	**146 849**	**140 411**	**136 200**

Due to a reduction in the market prices received for Japanese amberjack (*S. quinqueradiata*), yellowtail production in Japan is diversifying into the culture of greater amberjack (*S. dumerili*) and yellowtail amberjack (*S. lalandi*) (Figure 120). Greater amberjack are cultured commercially in Japan, Taiwan Province of China (www.aquatechgroup.com/AtgWeb/TaiwanFish.HTM), Republic of Korea, Hong Kong, Viet Nam, and Spain. This species has been cultured in Spain since 1999 in a limited way for establishing its feasibility and testing its market potential.

Research is currently being undertaken in Italy, Greece, France, Malta, and Croatia. The culture of greater amberjack in Japan has been growing rapidly (Nakada 2000), even though production data on *S. dumerili* does not yet show up significantly in FAO statistics (FAO 2002a); Table 61 shows the total number of greater amberjack reared there.

Commercial production of *S. dumerili* was active at Las Comunidades Autónomas de Murcia y Baleares in Spain from 1985 to 1999, when it ceased (J. Delgado, pers. comm. 2002). The main limiting factor is the source of juveniles for on-growing; these always come from local wild

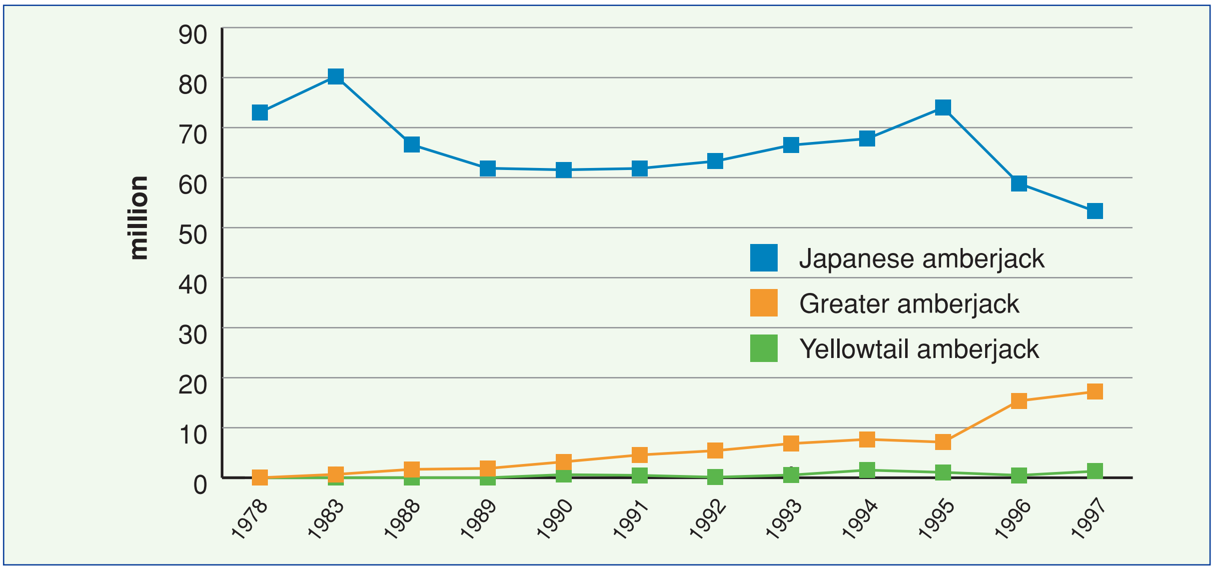


Figure 120. Japanese production of yellowtails (number of fish) (Nakada 2000, modified)

Table 61. Numbers of greater amberjacks reared in September by Prefecture
(Source: Japan Seawater Fisheries Culture Association)

Prefecture	1996	1997	1998	1999	2000	2001
	Numbers of fish ('000)					
Shizuoka	7	1	-	-	-	-
Ishikawa	-	-	-	-	-	-
Fukui	2	-	-	-	-	-
Mie	-	-	-	-	1	1
Kyoto	-	-	-	-	-	-
Wakayama	7	-	-	2	-	7
Hyogo	-	-	-	-	-	-
Tottori	-	-	-	-	-	-
Shimane	-	-	-	-	-	-
Yamaguchi	-	-	-	-	-	2
Tokushima	5	17	5	5	33	8
Kagawa	72	120	88	-	29	-
Ehime	334	325	515	444	710	884
Kochi	469	398	525	815	1 378	1 388
Fukuoka	-	-	-	-	-	-
Nagasaki	-	20	-	-	239	14
Kumamoto	102	90	71	418	784	469
Oita	112	190	151	230	246	407
Miyazaki	1 622	1 280	1 504	1 366	2 175	1 846
Kagoshima	6 437	7 023	6 165	6 264	10 065	9 188
Others	-	-	-	-	4	-
Total	**9 169**	**9 464**	**9 024**	**9 544**	**15 664**	**14 214**

populations, and are scarce or extremely expensive, € 2-3 each for 50g fish (A. García Gómez, pers. comm. 2002). The maximum production was 31 tonnes, in 1991. Hong Kong has cultured greater amberjack, catching "seed" from the natural population and producing 167 tonnes, valued at US$ 1 207 000 in 1995 (www.fao.org/docrep/W6937E/W6937e06.htm). In Taiwan Province of China, the culture of greater amberjack started around Tainan and Penhu-dao, and large-scale production should begin shortly, using large floating net pens. Juvenile greater amberjack are caught with juvenile Japanese amberjack ("*mojako*"), and at one time the two species were cultured together (Nakada 2000).

The first experimental culture of yellowtail amberjack (*S. lalandi*) is under way in Australia, New Zealand and Ecuador (Benetti 1997; Benetti, Garriques and Wilson 1998). In 2001, South Australia produced 18 tonnes of this species (Anonymous 2001). Commercial-scale marine fish culture began in Chile in 1991, and in 1997 carangids (*Seriola* spp.) were still in an experimental phase of culture.

Culture systems

Most yellowtail farming is carried out in floating cages. In choosing the location for cage sites, circulation, temperature and pollution must be taken into account. The use of cages, both for rearing and for on-growing purposes, has been the key to the success of yellowtail farming, and is being adopted to a number of other types of fish culture. Floating cages combine the advantages of small and large enclosures (Pillay 1995).

The Japanese techniques for the culture of greater amberjack (*S. dumerili*), which are called "*kampachi*", are the same as those used for Japanese amberjack (*S. quinqueradiata*) (Harada 1965; Cimmino 1973; Müller-Feuga 1972; Giovanardi 1981; Peña 1981; Nakada and Murai 1991; Grau 1992, Ikenoue and Kakufu 1992). The fry are collected from the wild, and carefully sorted out according to size, in order to prevent cannibalism, a behavioural pattern that becomes apparent after 23 days of life, according to Sakakura and Tsukamoto (1996). Juveniles of 2-10 g are firstly cleaned for parasites by immersion in freshwater. Then they are put in a 2 x 2 x 2 m net cage, with a stocking rate of 1 600–2 000 fish/m^3. At 50 g (after 4-6 weeks) the fish are graded again, in order to prevent cannibalism. The on-growing net cages are square or circular, with wood, metal or polyethylene frames. The sorted fry are reared separately in small floating, fine-mesh net-pens (2-50 m^2) which have a depth of 1-3 m (Pillay 1995). The fish grow rapidly. Fingerlings stocked in May/June grow to 200-700 g by August and 600-1 600 g by October; by the end of December they reach a weight of 700-2 000 g.

Japanese amberjack were originally cultured in Japan in ponds, coastal lagoons or lakes, but later, pen culture systems in coastal areas fenced off by nets were used. The development of cage systems started in 1954. Some indication of the number of facilities in 1998 in Japan are given in Table 62.

Table 62. Yellowtail aquaculture facilities in 1998 (M. Mahita, pers. comm. 2002)

Enclosure aquaculture system		Enclosure aquaculture by net partition		Net cage aquaculture system	
No. of facilities	Area (1 000m^2)	No. of facilities	Area (1 000m^2)	No. of facilities	Area (1 000m^2)
2	48	87	285	15 092	1 745

Most of present-day production comes from cages (floating or submersible) and some from ponds. Floating cages are used in sheltered sea areas. Harada *et al.* (1984) stated that net pens were typically 8 x 8 x 8 m, which were less expensive than the previously described systems. This method has the advantages of high water exchange rates, lower maintenance costs, and easier fish harvesting. Cage systems have been adopted by almost all farmers (Nakada 2000). Cage culture does require frequent water changes initially because of bio-fouling that restricts water exchange. The problem was overcome through the use of tri-butyl tin (TBT), which was ultimately banned because of toxicity problems. New chemicals and anti-foulants are now being used.

In Japan, increasingly larger cages have been developed with 15 x 15 x 15 m commonly being used, and the frameworks/collars changing from wood to metal and polyurethane pipes. Even larger cages are being developed - up to 50 x 50 x 50 m. For large fish like Japanese amberjack, sufficient space for exercize is necessary for the development of firm muscle tissue. The recommended densities in floating cages are shown in Table 63. Modifications may be necessary where environmental conditions may cause problems to occur, such as poor flushing rates, shallow water, etc. The use of large cages promotes higher quality meat with correct fat levels that are appreciated by the consumers. In the Republic of Korea, *S. quinqueradiata* is also cultured in floating cages: juveniles are stocked in floating nylon net cages, ranging from 2 to 50 m^2 and 1-3 m in depth. Growing to market size is carried out in cages with an area of 35-100 m^2 and a depth of 3-6 m.

Table 63. Recommended stocking density of Japanese amberjacks in floating net pens (Nakada, 2000 modified)

Size classification[1]	Pen size (m^3)	Av. body weight (g)		Numbers of fish stocked			Total body weight (kg)		Density (kg/m^3)	
		Initial	Final	Initial	Survival (%)	Final	Initial	Final	Initial stocking	Final harvest
"*Mojako*"	5x5x5 (125 m^3)	0.5	20	30 000	90	27 000	15	540	0.12	4.32
		2.0	50	20 000	90	18 000	40	900	0.32	7.20
		5.0	100	15 000	90	13 500	75	1 350	0.60	10.80
		10.0	200	10 000	90	9 000	100	1 800	0.80	14.40
Young "*hamachi*"	8x8x8 (512 m^3)	20	300	20 000	95	19 000	400	5 700	0.78	11.13
		20	400	20 000	95	19 000	400	7 600	0.78	14.84
		50	500	18 000	95	17 100	900	8 550	1.75	16.69
		50	600	18 000	95	17 100	900	10 260	1.75	20.03
		100	700	16 000	95	15 200	1 600	10 640	3.12	20.78
		100	800	16 000	95	15 200	1 600	12 160	3.12	23.75
		200	900	14 000	95	13 300	2 800	11 970	5.46	23.37
		200	1 000	14 000	95	13 300	2 800	13 300	5.46	25.97
"*Buri*"	10x10x10 (1 000 m^3)	600	3 500	7 000	97	6 790	4 200	23 765	4.20	23.77
		800	4 500	6 000	97	5 820	4 800	26 190	4.80	26.19
		1 000	5 000	6 000	97	5 820	6 000	29 100	6.00	29.10
		1 200	6 000	5 000	97	4 850	6 000	29 100	6.00	29.10
		1 200	5 500	5 000	97	4 850	6 000	26 675	6.00	26.68
		1 400	6 500	4 000	97	3 880	5 600	25 220	5.60	25.22
3-year old "*buri*"	10x10x10 (1 000 m^3)	1 200	3 500	5 000	97	4 850	6 000	16 975	6.00	16.98
		1 200	4 000	4 500	97	4 365	5 400	17 460	5.40	17.46
		1 500	3 500	4 000	97	3 880	6 000	13 580	6.00	13.58
		1 500	4 000	3 500	97	3 395	5 250	13 580	5.250	13.58

1 These terms are defined in the first paragraph of this chapter.

The performance of marine fish raised in floating cages varies considerably. Exact weights of individual "*mojako*" are not usually determined before stocking. Records are developed from the total weight of the fish being stocked, which is divided by the estimated total number of fish to determine the average weight. During the culture period, the number of "*mojako*" in each cage is estimated by subtracting mortalities as they occur. This data is used by farmers to calculate the daily amount of feed (Nakada 2000).

Optimum sites for young Japanese amberjack and greater amberjack culture should have water temperatures higher than 22°C. Nakada (2000) has found that greater amberjack can grow faster and with better feed efficiency than Japanese amberjack if the water temperatures are higher than 17°C. The optimal temperature range is between 24-29°C. Temperatures below 9°C and above 31°C can prove lethal for both species. Water temperatures vary in the areas where Japanese amberjack culture is carried out: so, in each region, farmers have developed specialized ways of rearing that take water temperature fluctuations into account. Table 64 shows water temperature characteristics for each Japanese region, and the percentage of the year when optimum range/growth occurs. The optimum salinity range for Japanese amberjack is 29.8-36.3‰; the effect of various dissolved oxygen levels is shown in Table 65.

Table 64. Characteristics of yellowtail culture areas (Nakada 2000, modified)

Region	Water temperature (°C)	Proportion (%) of the year when optimum growth occurs	Comments
Okinawa and Kagoshima	20-24	>75	>6 kg obtained in 2 years
Kyushu area (Kumamoto and Nagasaki)	17-19	50	>70% of the Japanese amberjack are reared for 3 years
Honshu area (Shizuoka and Yamaguchi)	18-19	50-60	Reared for more than three years (short autumn)
Seto Inland Sea	17	<50	Fish transferred to Kochi and Miyazaki for overwintering

Table 65. The behaviour of Japanese amberjacks at various dissolved oxygen (DO_2) concentrations (Nakada 2000, modified)

Fish condition	DO_2 mg/l	DO_2 % saturation
Active feeding	>5.7	>70
Decreased feeding	4.3-5.7	50-70
Unusual activity	2.9-4.3	40-50
Respiration difficulty	1.4-2.9	20-40
Suffocation and death	<1.4	<20

Since there is no domestic artificially reared seed, *S. dumerili* juveniles for capture-based aquaculture in Taiwan Province of China are mainly imported from Hanhai Province, southern mainland China. With a maximum size of 1.5-2 m, these fish can grow to 1 kg during the first year in sea cages and reach 5-7 kg after the second year. The major feed used is trash fish; local feed companies are still working on the development of artificial feed to replace trash fish. In 1997, 1.4 million of capture-based fry were transferred from mainland China. The fry (2.5-3.0 cm) price was once high (US$ 1.0-1.5/"seed") but dropped to US$ 0.4-1.0/fry in 1997. Larger fry (10-12 cm) cost US$ 2.9-4.5 each (www.aquafind.com/articles/seed.html). In Viet Nam, *S. dumerili* is cultured on an experimental basis. In Son Tra peninsula, greater amberjack have been cultured in 4.5 m^2 square cages, at a density of approximately 5 000 fish/cage (Pillay 1995).

Several studies about the on-growing of *S. dumerili*, beginning with juveniles (approximately 100 g) captured in the Mediterranean Sea and maintained until they reach a weigh of 1 kg (after approximately one year), have been carried out in Spanish waters (Boix, Fernández and Macia 1993; Gárcia-Gómez and Ortega-Ros 1993; Pastor *et al.* 2000), in Italian waters (Cavaliere *et al.* 1989; Lazzari and Barbera 1989b; Giovanardi *et al.* 1984; Greco *et al.* 1993; Porrello *et al.* 1993) and in Croatian waters (Benovic 1980); excellent growth rates have been obtained at all locations. Young fish have been reared in concrete tanks (Cavaliere *et al.* 1989; Lazzari and Barbera 1989b; García 1993a,b,c; García *et al.* 1993; Greco *et al.* 1993) and in net cages (Giovanardi *et al.* 1984; Navarro, Belmonte and Culmarex S.L. 1987; Grau 1992; Boix, Fernández and Macia 1993; Porrello *et al.* 1993). The initial stocking rate for juveniles is 2-3 kg/m^3, and the biomass can reach 10 kg/m^3 when individual fish are 1 kg in weight (Grau 1992). Greater amberjack has been cultured in sea cages in Spain since 1980, mainly in the Balearic Islands, Murcia and along the Tarragona coast. In the Balearic Islands the fish can reach 1.2 kg after nine months (Grau *et al.* 1996). Low water temperatures in the Mediterranean Sea during the winter months restricted growth, but when the water temperature reached 20°C in early May and continued above this level until October, growth became extremely fast. The young fish were fed on a diet of trash fish and reached 300-500 g by the end of the first year, and >2 kg by the end of the second. The biomass in the large grow-out cages was maintained at 5 kg/m^3. In Italy, both immature and adult specimens are commercially important. They have been the subject of rearing experiments in concrete ponds (Lazzari and Barbera 1989a) and floating cages (Giovanardi *et al.* 1984; Porrello *et al.* 1993). Due to its biological features, *S. dumerili* seems better adapted to rearing in cages than in tanks (Porrello *et al.* 1993).

Feeds and feeding regimes

Several papers have been published about the food and feeding habits of young and adult greater amberjack (*S. dumerili*) (Lazzari and Barbera 1988, 1989a; Grau *et al.* 1992; Mazzola *et al.* 1993; Badalamenti *et al.* 1995; Matallanas *et al.* 1995; Pipitone and Andaloro 1995). It has also been reported (Nikolwsky 1963; Wooton 1991), that *S. dumerili* undergoes a marked diet shift during its development. The few commercial farming experiences with *S. dumerili* in the Mediterranean, as in the case of the Japanese amberjack in other regions, have been based on frozen, low-cost raw fish, e.g. *Sardinella aurita*, *Boops boops*, *Trachurus trachurus*, *Scomber scombrus*, *Engraulis encrasicholus* and *Sardina pilchardus*. Many research studies about the on-growing of *S. dumerili* in tanks and in cages have used raw fish as food (Giovanardi *et al.* 1984; Navarro *et al.* 1987; Cavaliere *et al.* 1989; Lazzari and Barbera 1989b; Grau 1992; Boix, Fernández and Macia 1993; García 1993a; García, Moreno and Rosique 1993; Greco *et al.* 1993; Porrello *et al.* 1993, Mazzola *et al.* 1993). Greater amberjack seems to find fish scraps more appetising than pellets (Mazzola, Favaloro and Sarà 2000). Fish fed *ad libitum* with raw fish have a food conversion rate (FCR) of 5-7:1. Growth and feeding parameters in greater amberjack are influenced by fish age and water temperature (García 1993c), as in *S. quinqueradiata* (Harada 1965). García, Moreno and Rosique (1993) suggested a lower feeding rate than satiety for young *S. dumerili* at optimal water temperatures (20-25°C). At temperatures below 15°C fish stop feeding (García 1993a,b); they cease to move at below 11°C, and die in few days at 10°C (Benovic 1980). Table 66 provides some information on the growth and feeding rates of greater amberjack.

Table 66. Growth and feeding parameters of captive greater amberjacks *(Seriola dumerili)* fed with raw fish (García 1993c, modified)

Age	Weight (g)	Length (cm)	DGR[1,3]	SFR[2,3]
1	1 000 -1 100	35-45	0.8-1.1	1.7-5.6
2	3 000-3 200	60-65	0.3-0.4	0.4-2.6
3	5 000-5 200	70-75	0.2	n.a.
4	8 000-10 000	85-95	n.a.	n.a.
5	11 000-13 000	95-105	n.a.	n.a.

1 DGR = Daily growth rate (%).
2 SFR = Specific feeding rate (%).
3 Note: DGR and SFR vary with the seawater temperature.

In Japan, farmers use the same diets for feeding fry, fingerlings and adults of all yellowtail species. "*Mojako*" are fed *ad libitum* or at 80% of satiation. The feeding frequency is 8-10 times/day on stocking, 2-3 times/day later on, and 1-2 times/day later in the cycle; the daily quantity varies from 30% to 3% of body weight during the on-growing phase. FCRs of 7:1 are obtained with fish that weigh up to 1.5 kg, and 10:1 for fish up to 4 kg, based on a wet weight basis. On dry weight basis, the FCRs are 2.1:1 and 3.0:1 respectively (Pillay 1995).

Some farmers use anchovies, though this feed source is not recommended; continuous feeding with these fish can cause mortalities as a result of oxidation of the unsaturated fatty acids in anchovy flesh. The thiaminase contained in anchovy flesh has been found to cause vitamin B_1 deficiency in yellowtail (Pillay 1995). The problem can be avoided if a vitamin mix consisting of vitamins B_1, C and E is added to the diet to boost the vitamin B_1 level and prevent oxidation and fat-deterioration (Nakada 2000). The use of sardines as the sole feed for yellowtail has also led to nutritional disorders caused by unsuitable protein and energy levels. Recommended calorie/protein ratios are shown in Table 67).

Until 1985, frozen raw fish were used in Japan as the main food in the culture of Japanese amberjack (*S. quinqueradiata*) (Nakada and Murai 1991; Shimeno 1991). The use of frozen fish alleviated deterioration of the feed and reduced environmental pollution. Its use did not cause any ill effects and was better than feeding thawed sardines. The body composition of sardines, especially the fat content, changes dramatically, depending on the season and harvest area. Its lipid content also differs between sardines caught in the Pacific Ocean and in the Sea of Japan. While a good system for distributing sardines has been developed, making them readily available to fish farmers, there is no control over their fat content. Sato *et al.* (Nisshin Nasu Feed Research Laboratory, unpublished data) found a high linear correlation between the moisture and fat contents of sardines landed at Kyushu, Sanin and Kushiro. The amount of moisture and fat in the bodies of sardines are highly negatively correlated (moisture and lipid equation in

Table 67. Recommended calorie/protein ratio by season and size for Japanese amberjacks (Nakada 2000, modified)

Growth[1]	Av. weight (g)	Season	Month	Recommended C/P ratios in kcal (kJ)
"*mojako*"	0.2-10	Catching and acclimation	April-June	60-80 (251-335)
"*mojako*"	10-200	Acclimation and rearing	April-August	80-90 (335-377)
"*hamachi*"	100-800	High temperature period	May-September	90-100 (377-418)
"*hamachi*"	500-2 500	Low temperature period	September-March	100-120 (418-502)
Yellowtail	800-5 000	Rising temperature period	March-September	120-140 (502-586)
Yellowtail	>3 000	Descending temperature period	September-March	140-160 (586-669)

1 These terms are defined in the first paragraph of this chapter.

sardines: y = -1.138x + 90.121; x is the moisture content, which ranges from 57-74%; y is the crude fat content, which ranged between 25.3-59%; n=35; γ=0.9702). Fat content can therefore be estimated by measuring the moisture content of the sardines rather than having to make a direct measurement of crude lipid. This provides an easier method for small-scale farmers (Nakada 2000).

Research is being conducted in Spain using moist and "soft-dry" pellets as feed for young *S. dumerili*; this has resulted in better growth, survival and FCR, than those achieved using raw fish (García 2000).

In 1979, the Japanese Fisheries Agency started an important project to develop a moist pellet diet suitable for yellowtail culture. Its introduction failed until the early 1990s, because of the abundant and extremely cheap supply of domestic spot-lined sardine. However, fish farmers became aware of the severe damage to their environmental conditions that was the result of using trash fish instead of pellets. A new type of dry pellet diet that was produced in 1988, using extrusion machines, was found to be suitable for yellowtail culture (Nakada 2000). Figure 121 shows the amount of artificial feed used for yellowtail culture in Japan.

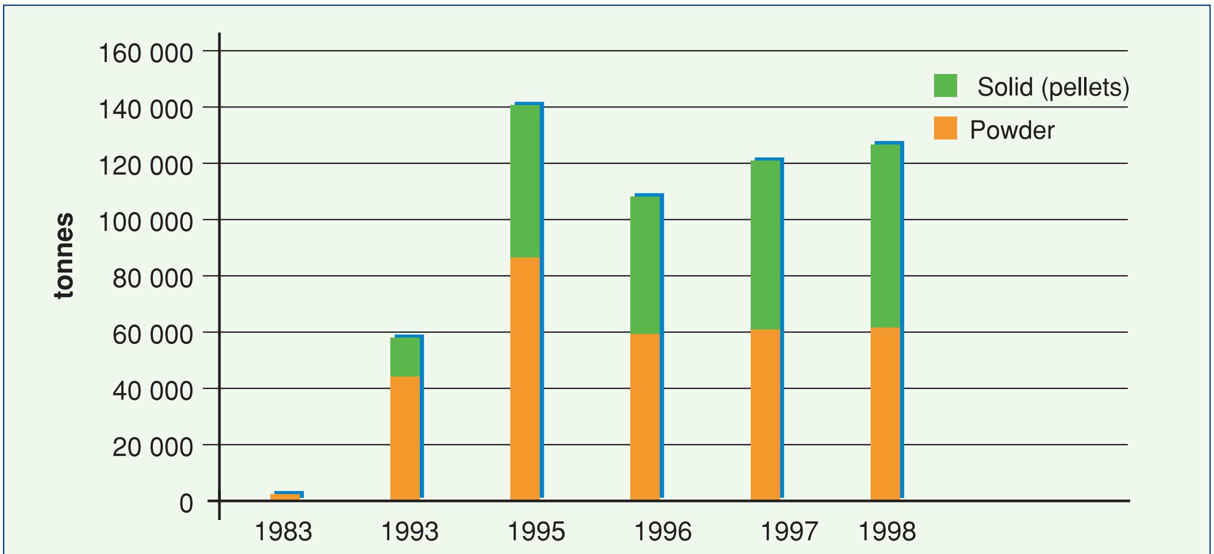


Figure 121. Total amount of artificial feeds used for Japanese amberjack culture in Japan (Nakada 2000, modified)

Several practical formulated feeds, e.g. the Oregon moist pellet (OMP), semi-moist pellets (SMP), "soft-dry" pellets (SDP), and extruded pellets (EP) have been developed; the latter two have only come recently into use. These formulated feeds have advantages and disadvantages. *S. dumerili* fed on OMP show lower mortality rates and more homogenous growth than those fed on raw fish (Di Bella, Genovese and Salvo 1991, 1994; García 1993a,b; Greco *et al.* 1993; García *et al.* 1995; Gonzalez *et al.* 1995); however, it is difficult to maintain the correct calorie-protein balance in larger pellets. At present the pellets do not supply enough energy for larger fish (Nakada and Murai 1991). However, this observation is recognized as being potentially out-dated since it is appreciated that extruded feed is now available for salmon, so the technology used for its production could be applied in the future to yellowtail feeds.

SMP have the same advantages as OMP, but in addition have stable nutritive values and are more hygienic, as they do not require fresh fish as a raw material. However, SMP cannot be used during periods of low temperature (Shimeno 1991).

SDP and EP have been successfully used in Japan, not only for the on-growing of *S. quinqueradiata* (Watanabe *et al.* 1991, 1992, 1993; Shimeno *et al.* 1993a,b,c,d,e; 1997b; Shimeno, Matsumoto and Ukawa 1997a), but also as a broodstock diet (Mushiake *et al.* 1995; Watanabe *et al.* 1996; Verakunpiriya *et al.* 1996, 1997). EP look very promising because they are cheaper, more nutritive, less polluting and require less labour and facilities for their preparation and storage (Nakada and Murai 1991; Shimeno 1991). EP formulations with crude lipid levels of more than 20% can be efficiently utilized by yellowtail. EP also have a high enough calorie content to meet the nutritional need of *Seriola* spp.; they are water stable, and do not deteriorate at normal temperatures, thus making possible the full-scale automatization of the capture-based aquaculture of yellowtail in offshore ocean sites (Nakada and Murai 1991). Yellowtail larger than 3 kg prefer raw fish to EP, however, and it is difficult to attain daily feeding rates of 2% with this type of feed, especially during winter. Nakada (2000) believes that the development of an extruded diet containing more than 25% lipid, and with pellets that weigh more than 30 g each, will be required for the economic production of yellowtail larger than 3 kg, especially during periods of low water temperature. Various feeding regimes and related production costs are shown in Tables 68 and 69.

During the 1980s in Japan it was common practice to add additional oils to feeds used in freshwater aquaculture, but the same oils could not be used for the marine species because there are significant differences in the fatty acid requirements of freshwater and marine species. Nakada (2000) developed suitable feed oils for marine species at the Aquafeed Division of the Nisshin Feed Co., Ltd. Commercial production trials with these oils produced yellowtail that had a similar lipid composition to wild fish. However, the quality of the oil containing high levels of HUFAs varied, so the Society of Aquaculture Feed Oil Investigation set up standards for feed oils recommended for aquaculture diets (Nakada 2000).

Table 68. Characteristics of the various types of feed used for different sizes of Japanese amberjack culture (Nakada 2000)

Feed type	Feed intake efficiency (%)	Range of FCR	Growth stage [1]
Minced raw fish	20-30	15.0-20.0	"*mojako*"
Minced raw fish	20-30	10.0-15.0	"*hamachi*"
Minced raw fish + binder	40-50	7.0-10.0	"*hamachi*"
Round raw fish	40-60	8.0-12.0	"*hamachi*"
Round raw fish	40-60	6.0-9.0	"*buri*"
Moist pellet 0	40-60	7.0-15.0	"*hamachi*" and "*buri*"
Moist pellet 30	50-70	5.0-12.0	"*hamachi*" and "*buri*"
Moist pellet 50	60-80	4.0-8.0	"*hamachi*" and "*buri*"
Moist pellet 100	70-90	3.5-8.5	"*hamachi*" and "*buri*"
High fat dry pellet	60-80	3.0-4.5	"*mojako*"
High fat dry pellet	70-80	4.5-6.5	"*hamachi*"
Extruded pellet	80-90	0.8-1.2	"*mojako*"
Extruded pellet	70-80	1.0-2.0	"*hamachi*"
Extruded pellet	60-70	1.8-3.5	"*buri*"

1 These terms are defined in the first paragraph of this chapter.

Owing to limitations that often affect the availability and sustainability of raw materials from marine sources, principally fishmeals and fish oils, the fish feed industry has undertaken extensive research into alternative raw materials that would meet requirements for the efficient cost-effective production of feed for farmed fish (Talbot 1998). Several papers have been published dealing with the partial substitution of fishmeal by other animal and plant protein sources in practical diets for *S. quinqueradiata*. Animal proteins from meat meal and meat and bone meal, together with plant proteins (mostly soybean meal but also corn gluten meal, rapeseed meal and malt protein flour) have been tested (Takii *et al.* 1990; Lee, Kang and Lee 1991; Shimeno 1991, 1992a,b, 1993a,b,c,d, 1997b; Shimeno, Matsumoto and Ukawa 1997a; Shimeno *et al.* 1995a,b; Masumoto *et al.* 1996; Ruchimat *et al.* 1997). In the future, it is expected that fishmeal, which is the main protein source in formulated feeds, will be substituted with soybean meal or poultry meal and a certain amount of fish oil will be added along with soybean oil or coconut oil (Nakada 2000).

Table 69. Feeding regimes and related production costs for yellowtails (Nakada 2000, modified)

Type of feed	Growth stage and average body weight (g)	Unit cost of feed (¥/kg)	FCR	Production cost (¥/kg)	Remarks
Minced raw fish (Sand eel)	"*mojako*" 5-50	125	8.4:1	1 050	Highly stable but high leaching
Minced raw fish (Spotlined sardine)	"*mojako*" 5-200	60	16.3:1	978	Unstable and high leaching
Minced raw fish (Spotlined sardine)	"*hamachi*" 50-2 000	65	12.1:1	787	Unstable and high leaching
Minced raw fish, plus binder	"*hamachi*" 50-2 000	70	6.8:1	476	Decreased leaching problem
Round raw fish, plus supplement	"*hamachi*" 500-2 000	60	7.6:1	456	Economical but small harvest
Round raw fish, plus supplement	"*buri*" 1 000-8 000	60	8.1:1	486	Economical but small harvest
Moist pellet* MP50 (50:50)	"*mojako*" 5-200	105	2.6:1	273	Technical difficulty in feed production
Moist pellet* MP30 (30:70)	"*hamachi*" 50-2 000	88	4.1:1	361	Economical and good for healthy fish
Moist pellet* MP0 (0:100)	"*hamachi*" 500-2 000	64	6.3:1	403	Unstable pellet but low feed cost
Moist pellet* MP100 (100:0)	All stages for medication	140, plus medicine	2.4:1	336	Used especially for medical treatment
High fat dry pellet (crude fat >12%)	"*mojako*" 5-200	170	1.8:1	306	Highest performance until the end of August
High fat dry pellet (crude fat >12%)	"*hamachi*" 50-2 000	160	2.7:1	432	Suitable for reduced feeding rate during the Winter
Extruded pellet	"*mojako*" 5-200	230	1.1:1	253	Highest growth and economical performance
Extruded pellet	"*hamachi*" 50-2 000	180	1.6:1	288	Low FCR during Winter
Extruded pellet	"*buri*" 1 000-8 000	170	2.7:1	459	Low feeding efficiency for large fish

* Formulated powder (¥ 135/kg); Frozen sardines (¥ 60/kg); Feed oil (¥ 170/kg)

Fish health and disease

The rapid expansion of finfish aquaculture has resulted in many problems, particularly in the production of quality "seed", the development of a suitable pelleted feed, the pollution of the culture areas and cultured fish diseases. Disease and health issues have become very important and their diagnosis and treatment is a major issue for all fish farmers. Knowledge of diseases in cultured yellowtail is restricted to Japan and a few Southeast Asian countries, where mariculture is intensively practized. Many important groups of bacteria have been reported to cause disease outbreaks in farmed marine finfish, resulting in serious economic losses to the industry, vibriosis being the commonest (Leong 1992). According to Ogawa (2002), the lack of knowledge on diseases in many other countries in the region is mainly due to the lack of trained manpower. In Japan, Sano (1998) reported that the major diseases occurring in cultured species in 1993 could be categorized according to their causative agents: 37 bacterial, 17 parasitic, 11 viral, 4 fungal, 1 concurrent, and 9 others.

Fish intensively cultured in floating net-cages are often heavily infected with monoxenous parasites, particularly the monogeneans (Ogawa 2002), while fish extensively cultured in net-enclosures or ponds generally harbour these parasites in low densities. The fry and fingerling of most species are highly susceptible to infections of protozoans, *Cryptocaryon irritans* and *Trichodina* spp., during the early stages of their introduction in floating net-cages. These infections represent the most serious risk to the industry owing to their high pathogenicity and resistance to conventional control methods. The management of farm diseases in Japan has caused a recent trend for increasing the size of cages and reducing stocking densities; these changes have resulted in a disease reduction and a health improvement.

The most important diseases of the Japanese amberjack (*S. quinqueradiata*) are *Enterococcus seriolicida*, *Streptococcus*, *Pasteurella piscida* (pseudotuberculosis), vibriosis, *Nocardia* and *Flexibacter* (Kusuda 1990; Nakada and Murai 1991; Egusa 1992; Kawakami *et al.* 1997) and a specific viral disease that affects fingerlings called "Yellowtail Ascite Virus" (YAV) (Ishiki, Kawai and Kusuda 1989). With production increasing, outbreaks of these diseases will probably also affect the greater amberjack (*S. dumerili*). The most serious problem in recent years has been the iridovirus infection, introduced from Southeast Asia, which has caused mass mortalities in yellowtail (Nakada 2000). A recent study reported an increasing number of disease problems in recent years (Yokoyama and Fukuda 2001); about 20 species of parasites have been found in cultured yellowtail. Of these, the myxozoans *Ceratomyxa seriolae* and *C. buri* were found in the gall bladder of cultured yellowtail.

As at March 1997, there were 25 approved drugs marketed in Japan for the treatment of bacterial diseases and used under the control of the Ministry of Agriculture, Forestry and Fisheries. Their use is limited and regulated by standard procedures. The Central Pharmaceutical Affairs Council is involved in licensing and evaluating drugs as to their safety, efficacy and residues prior to marketing aquatic products. Even after approval, drugs are used in aquaculture under the strict supervision of licensed veterinarians. No preventive measures or therapeutants are available to cope with viral infections. In 1997, a licence was given to manufacture an oral drug against lactococcosis occurring in cultured Japanese amberjack (*Seriola quinqueradiata*). Besides the use of vaccines or antimicrobial agents, available experience suggests that the addition of an "UGF" (unidentified growth factor) to fish feeds at a level of 2% has been found to support healthy growth while significantly inducing high non-specific hematocrit values (Sano 1998; Nakada 2000).

Vibriosis has caused severe losses in recent years among cultured yellowtail at some cage farms in the Republic of Korea. Among the bacteria isolated from the diseased yellowtail, *Vibrio* sp., found in the kidney was considered to be the causative organism. In August 1999 an outbreak of VSN (viral splenic necrosis) was reported in Hadong (Kyongnam province, Republic of South Korea) in Japanese amberjack (www.seafood.pknu.ac.kr/~fishpath/recent%20outbreak01.htm).

In the Mediterranean area, even where the on-growing of greater amberjack (*S. dumerili*) has shown good results in terms of excellent growth rates (García-Gómez and Ortega-Ros 1993; Lazzari and Barbera 1989b; Boix, Fernández and Macia 1993; García, 1993a,b,c; García, Moreno and Rosique 1993), their culture is compromised by several pathologies, mainly parasitic diseases. These have been reported on greater amberjack in Mediterranean countries by Crespo, Grau and Padrós (1990, 1992), Genovese *et al.* (1992), Grau (1992), Grau and Crespo (1991), and Grau *et al.* (1993). Since larval rearing is not achieved in the Mediterranean area, on-growing is directly dependent on the capture of wild juveniles from the sea; thus the introduction of parasitic diseases from the wild into the culture facilities is hard to avoid (Grau *et al.* 1999). In the Balearic Sea, a total of 15 parasites have been found, belonging to Myxozoa, Monogenea, Trematoda, Nematoda, Copepoda and Isopoda. The most important were *Myxobolus buri* and the gill fluke *Heteraxine heterocerca*, typical of yellowtail and responsible for the most severe diseases (Paperna 1995). Other pathogenic species are *Paradeontacylix* spp., which were responsible for mass mortalities of cultured greater amberjack of the 0^+ class (Grau *et al.* 1999). Recurrent occurrences of mass mortalities have been occurring in the 0^+ age class since 1988, due to epitheliocystis and sanguinicoliasis (December to March) and pseudotuberculosis (October to January). Icthyophoniasis, vibriosis, trichodiniasis and equinostomatidiasis have also been reported in *S. dumerili* (Genovese *et al.* 1992; Grau 1992).

In Japan, where "seeds" of the greater amberjack are mainly imported from Asian countries (Wakabayashi 1996), many exotic micro-organisms and parasites have been found, probably introduced together with the fish eggs and larvae imported for aquaculture. In Japan the monogenean *Neobenedenia girellae* causes mortalities due to heavy infection; the unregulated importation of greater amberjack fry (*S. dumerili*) to Japan appears to have been the source of this parasitic infection since 1991 (Ogawa *et al.* 1995). A sudden outbreak of a disease caused by the trematode blood fluke *Paradeontacylix* occurred in May 1993 among net-cage cultured greater amberjack that had been imported from Haisa, China, a few months before the onset of the disease (Ogawa and Fukudome 1994). The main diseases reported in *S. dumerili* in Japan are epitheliocystis (Crespo, Grau and Padrós 1990) and parasitic infections like microsporidiasis and *Benedenia seriolae*. *B. seriolae* is strongly host specific to *Seriola* spp. (Yoshinaga *et al.* 2002). Problems have also been found when rearing yellowtail and related species in warm waters, due to muscle parasites and ciguatera. Table 70 shows a synthesis of the principal pathogens of cultured yellowtail.

Both yellowtail amberjack and greater amberjack, especially those weighing over 5 kg, are sometimes known to ingest dinoflagellates which can cause ciguatera poisoning; however, when raised in cages and fed formulated feeds, they may not accumulate the poison. It is important to make sure that cultured fish will not contain ciguatera-toxin (Nakada 2000).

In the waters south of Kagoshima, aquaculture of these species is impossible because of "*kudoa*" parasitism in the muscles and internal organs. In some cases, cultured juvenile Japanese amberjack and greater amberjack have been killed by an iridovirus infection, which was originally introduced with wild juveniles imported from tropical areas. Cultured fishes are more vulnerable to diseases than wild fish because they are always under a degree of stress.

Table 70. Specific pathogens of cultured yellowtails

VIRUSES
Iridovirus
➔ Yellowtail Ascite Virus (YAV)
➔ Viral Splenic Necrosis (VSN)
BACTERIA
➔ *Enterococcus seriolicida*
➔ *Streptococcus* sp.
➔ *Pasteurella piscida* (pseudotuberculosis)
➔ *Vibrio* sp.
➔ *Flexibacter* sp.
➔ *Nocardia kampachi*
➔ *Nocardia* sp.
PARASITES
Protozoa
➔ *Cryptocaryon irritans*
➔ *Trichodina* sp.
Myxozoa
➔ *Ceratomyxa seriolae*
➔ *C. buri*
➔ *Myxobolus buri*
Monogenea
➔ *Benedenia seriolae*
➔ *Neobenedenia girellae*
➔ *Heteraxine heterocerca*
Trematoda
➔ *Paradeontacylix* spp.
Nematoda
Copepoda
Isopoda

Another severe problem is related to the presence of toxic algal blooms, which can affect marine fish farming. Oxygen depletion may occur under cages, due to decomposition of accumulated waste materials. During the autumn, the oxygen-depleted layer may rise due to convection and cause oxygen depletion and associated mortalities in cages. Eutrophication in culture areas can also lead to the development of "red tide" phytoplankton blooms, which have also caused severe mortalities (Nakada 2000). In 1957, large-scale red tides began to be reported in the Seto Inland Sea of Japan. Since 1964, these red tides, due to harmful marine phytoplankton, have spread throughout the Inland Sea of Japan. In the summer of 1970, a red tide of *Chattonella antiqua* caused the death of 500 000 yellowtail, valued at ¥ 620 million (Table 71). Yellowtail aquaculture in the Seto Inland Sea has continued to suffer from the outbreaks of red tide of

Chattonella spp. In studies on the effect of *Chattonella* on the gills of Japanese amberjack it was found that fish dying from *Chattonella* exposure showed many types of gill lesions, while those of fish dying from environmental hypoxia showed very few lesions, thus demonstrating that the branchial oedema was caused by *Chattonella* and not by hypoxemia. This emphasises that, along with the promotion of aquaculture, the establishment of monitoring systems for red tides, and efforts to remove its causes, are urgently needed (Ono *et al.* 1998; Hishida, Ishimatsu and Oda 1999; Fogg 2002).

Table 71. Reports of some cases of "red tide" in yellowtail farms in Japan

Date	Area	Cultured species	Phytoplankton species	Loss (quantity)	Loss (value)
1970	Inland Sea	Japanese amberjack	*Chattonella* spp.	500 000 fish	¥ 620 million
1972	not specified	Japanese amberjack	n.s.	n.s.	US$ 47 million
1977	not specified	Japanese amberjack	n.s.	n.s.	US$ 20 million
1978	not specified	Japanese amberjack	n.s.	n.s.	US$ 22 million
1987	not specified	Japanese amberjack	n.s.	n.s.	US$ 15 million
2000	Yatsushiro Sea	Greater amberjack	*Heterosigma* spp. *Cochlodinium polykrikoides*	63 tonnes	¥ 81 million
2000	Yatsushiro Sea	Japanese amberjack	*Heterosigma* spp.; *Cochlodinium polykrikoides*	22 tonnes	¥ 13 million

Harvesting systems

The minimum market size for Japanese amberjack starts at approximately 300 g; fish of this size can be harvested (Figure 122) from August, after a growth of about 4 months. The optimum size is about 1.2 kg, normally harvested from October to December. Seines and dragnets are used for harvesting from ponds and enclosures, but harvesting from cages is undertaken with dip nets and similar simple devices (Pillay 1995). Fish are fasted before harvesting, thus allowing ingested feeds to be evacuated. This reduces oxygen consumption and lessens the water pollution caused by evacuation during transport. The result of pre-harvest fasting is an improvement in the quality of the fish. In order to maintain the freshness of the product as long as possible, the fish should be killed immediately after being taken from the water by severing the *medulla oblongata*. They should be bled by cutting the caudal artery with a knife. If it is impossible to treat the fish individually they should be dumped into a tank with a large amount of chipped/slush ice. If the moribund state is prolonged or the fish are shipped without enough chilling, *rigor mortis* will start earlier and reduce product quality (Nakada 2000).

Figure 122. Yellowtail harvesting (Photo: M. Nakada)

There is a great demand for live fish, which fetch a higher price. Those who farm fish have an advantage over those involved in capture fisheries because most of the fish can be caught and transported alive. Fish are usually taken to markets by boat or trucks, stored in canvas tanks. There are very few detailed records of the economics of yellowtail culture; like other kinds of farming, costs and earnings are strongly dependent on local conditions, the technology employed and farmers' skill and experience (Pillay 1995).

Marketing

All three species of *Seriola*, greater amberjack, Japanese amberjack and yellowtail amberjack, have good market demand, mainly in Japan. Figure 123 shows the trend in the value of farmed yellowtail globally. About 99% of the aquaculture production of yellowtail is within Japan. There is no clear trend in the value of this production, which was about US$ 1.2 billion at the end of the decade. General trends in the unit value of farmed yellowtail in Japan and the Republic of Korea are given in Table 72. The main cultured species is Japanese amberjack (*S. quinqueradiata*); according to Nakada (2000), farmed production is typically in excess of 140 000 tonnes/year (Figure 124).

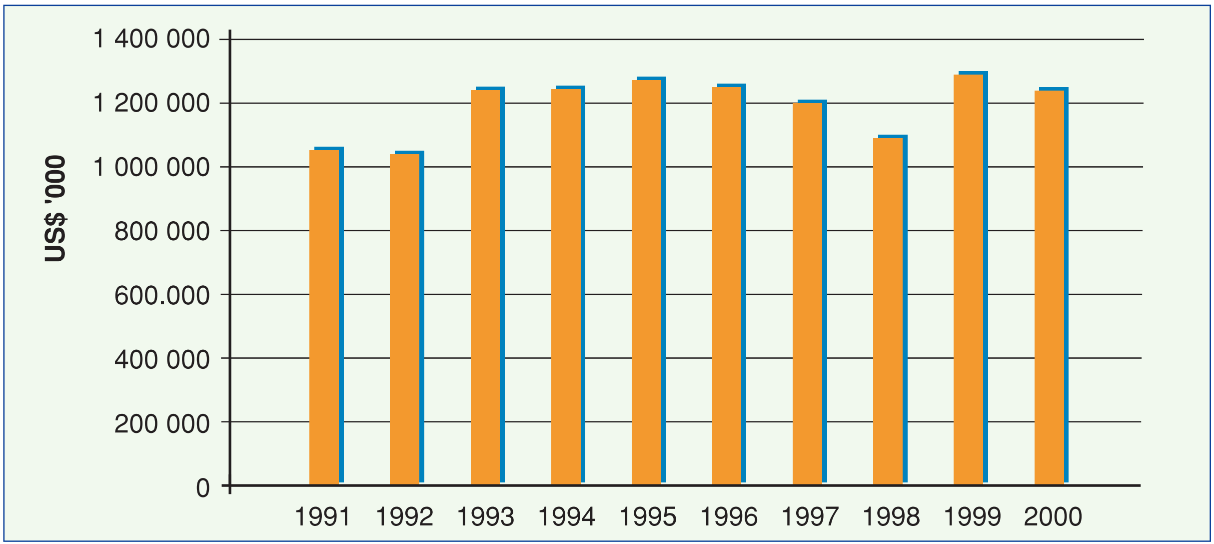


Figure 123. Trend in the global value of cultured yellowtails, 1991-2000 (FAO 2002a)

Table 72. General trends in the value of farmed yellowtails (US$/kg) in Japan and the Republic of Korea, 1991-2000 (FAO Fishstat Plus 2002)

Year	Japan	Republic of Korea
1991	6.5	5.9
1992	6.9	10.3
1993	8.7	2.9
1994	8.3	13.1
1995	7.5	13.3
1996	8.5	13.4
1997	8.6	10.0
1998	7.4	5.9
1999	9.1	7.6
2000	9.0	8.9

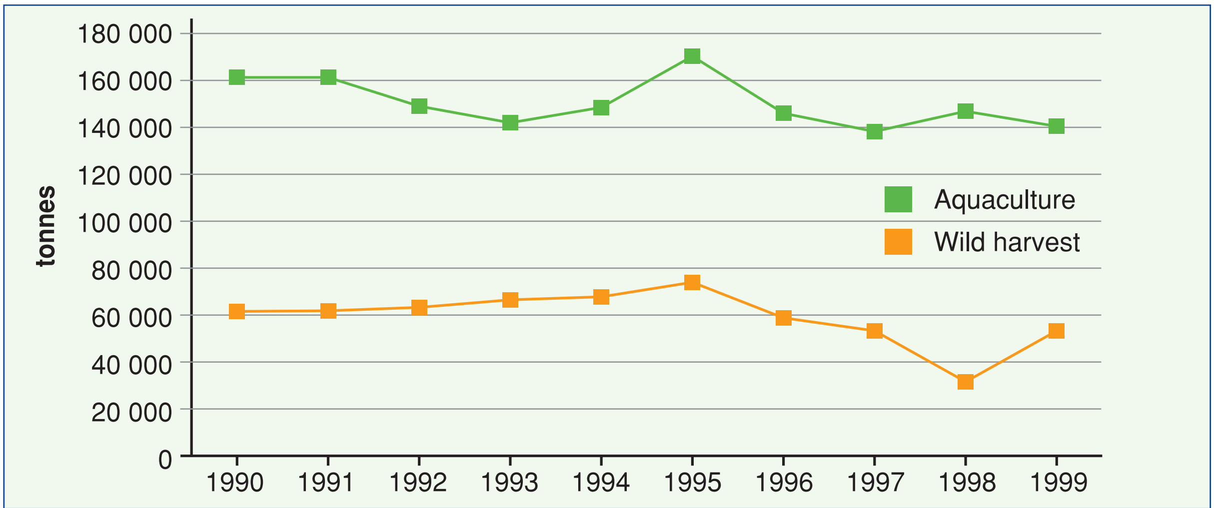


Figure 124. Aquaculture production *versus* the wild catch for the Japanese amberjack *(Seriola quinqueradiata)* (Nakada 2000, modified)

Since the 1980s, Japanese yellowtail farmers have had a difficult time with increasing production costs due to the rising costs of feed (caused by a drastic decline in the volume of sardines caught in Japanese waters), a poor supply of juvenile Japanese amberjack ("*mojako*"), and the stagnant Japanese economy. At the same time, the more valuable species, greater amberjack (*Seriola dumerili*) and yellowtail amberjack (*Seriola lalandi*), have become more attractive to fish farmers, and since 1995 the number of "*mojako*" stocked has declined. The traditional culture of Japanese amberjack, which used to be highly profitable, is facing difficulties today; farmers are trying to introduce new species such as those previously cited to make the capture-based culture of yellowtail more profitable (Doi 1991; Nakada 2000).

In Japan, the strongest competitor to cultured Japanese amberjack are small wild "*buri*", typically 50 to 60 cm in body length, which are caught in set nets. If a large quantity of young "*buri*" are landed at one time, the market price drops as low as ¥ 200-300/kg, while ¥ 800/kg or more is the lowest price for cultured fish (Figure 125). In Japan, prices for 20 g "*mojako*" in 1992 were ¥ 100-120 (average ¥ 5 500/kg) and ¥ 200-250 for 30-40 g juveniles (average ¥ 6 429/kg), depending on the time of the year and availability. After rearing, these fish were sold 2 years later for ¥ 800-1 200/kg (Nash 1995). By 1998 the "*mojako*" price had risen to ¥ 15 000/kg, the average production cost for a yellowtail adult was ¥ 750/kg, and market prices for an adult yellowtail reached ¥ 1 050/kg (M. Mahita, pers. comm. 2002). Generally, a 20 g "*mojako*" reaches 3.5 kg (the average market size) in around 2 years. A comparison of production trends and profits is provided in Table 73.

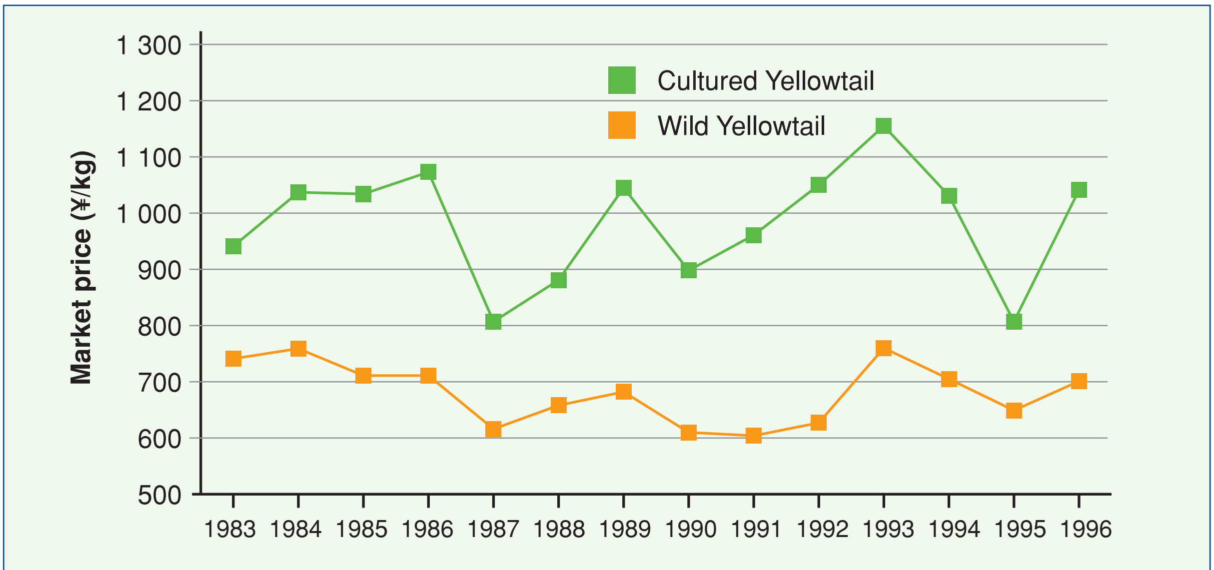


Figure 125. Market price for cultured and wild Japanese amberjack "*buri*" (Nakada 2000, modified).

Table 73. Production costs and profit trends for Japanese amberjack culture in Japan in 1992 and 1998 [derived from Nash (1995) and M. Mahita, pers. comm. (2002)]

Year	Cost of each "*mojako*" (¥)	Production costs (¥/fish)	Total production costs (¥/fish)	Market value (¥/fish)	Potential profit (¥/fish)
1992	300	1 140	1 440	3 500	2 060
1998	750	1 500	2 250	3 675	1 425

Greater amberjack aquaculture has been growing rapidly and this species now rivals Japanese amberjack. In 1998, the price of greater amberjack juveniles was ¥ 500/kg for 50 g fish and ¥ 1 500/kg for 600 g fish. Japan, via Hong Kong, has been importing wild juveniles caught in China and Viet Nam since 1986 (Nakada 2000). Now, because of its high quality, greater amberjack usually command much higher prices in Japan than cultured Japanese amberjack in wholesale markets (¥ 800-1 300/kg *versus* ¥ 600-900/kg, as shown in Table 74). Yellowtail amberjack meet with the highest favour as a "*sashimi*" (Nakada 2000). This species is also becoming a valuable new species for aquaculture in South Australia, but other countries are watching closely and several are currently testing this species.

Table 74. Market conditions for the three yellowtail species cultured in Japan (Nakada 2000)

	Japanese amberjack *(Seriola quinqueradiata)*	Greater amberjack *(Seriola dumerili)*	Yellowtail amberjack *(Seriola lalandi)*
Market size	Up to 6 kg for fillets; 3.5-4.5 kg for "*sashimi*"	3.5-5.5 kg for "*sashimi*"	Up to 4.0 kg for fillets and "*sashimi*"
Price (¥/kg)	Producers: 600-900 Consumers: 1 200-2 500	Producers: 800-1 300 Consumers: 1 500-3 000	Producers: 700-1 200 Consumers: 1 500-3 000
Maximum size	Up to 15 kg	Up to 70 kg	Up to 50 kg
Number reared in 1997	53.3 million	17.2 million	2.5 million
Juvenile supply	Wild juveniles called "*mojako*"	Mainly wild juveniles and pre-feeding juveniles imported from China and Viet Nam	Large juveniles of about 700 g caught in waters in Goto Islands

As consumers have become more selective about product quality, farmers have started to concentrate on trying to produce higher quality fish. The branding of special yellowtail products has been shown to be effective in sourcing better markets. Stable product quality, obtained by discarding second grade fish and paying special attention to freshness, has become highly valued by the intermediate dealers. Sales have increased in supermarkets and retail fish stores, through the marketing of special brands produced by such organizations as the Kagawa and Kagoshima Federation of Fisheries Co-operatives. Kagoshima Prefecture is the top producer of both farmed Japanese amberjack and greater amberjack. Some of the fish processing facilities in this Prefecture obtained an approval by authoritative private verification organizations in 1998. Complying with the HACCP regulations, these facilities have been ensuring food safety and keeping a high level of hygiene control. The large-scale farming of the greater amberjack in Kagoshima Prefecture began in 1990, and Kagoshima is now the country's main producer. Greater amberjack marketed with the Kagoshima label have a high reputation with consumers. The fish are being consumed more and more as "*sashimi*", and is considered a delicacy in the Tokyo area.

The market for cultured fish in Japan can be divided principally into high class Japanese restaurants (that deal mainly with live fish), wholesale stores and supermarkets (dealing with fresh and frozen fishes), and direct delivery of processed fillets to individual restaurants and homes. Fish farmers are having difficulty making a profit now, owing to the stagnant economy and excessive competition among themselves. Recently, direct deliveries from the producer to the consumer have begun. The Internet, mail or fax can be used for ordering and reliable payment collection. Producers keep lists of reliable customers and can estimate future demands. Consumers have recognized the difference in the quality of the product, so this type of delivery system shows a promising future and could help stabilize fish farming.

In Spain, greater amberjack were cultured until 1999, when production stopped. At the current time there are no farms officially producing *Seriola* in that country. Some farms devoted to seabass/seabream or tuna are producing limited amounts to test the feasibility and market for commercial production. The main limiting factor is the source of juveniles for on-growing purposes. These always come from local wild populations, and are scarce or extremely expensive: € 2-3 each for 50 g *Seriola* (A. García Gómez, pers. comm. 2002).

South Australia is beginning to harvest yellowtail amberjack (*S. lalandi*) to satisfy increasing export demand. The two main markets for Australian "*hiramasa*" are for high quality "*sashimi*" in Japan and the USA, and as a table fish in Europe and Asia. "*Hiramasa*" is the second most popular "*sashimi*" product in Japan after tuna. It is also highly popular as a table fish in Europe. The marketing strategy is to promote a combination of both "*sashimi*" and table fish to achieve a good marketing balance. The fast growing kingfish (yellowtail amberjack) reach about 2-3 kg within 12-14 months, a suitable size for table fish. Alternatively, they can be grown out to 4-5 kg in 18 months for "*sashimi*". Studies are needed to ascertain the best profit ratios from "*sashimi*" and table fish. The South Australian Aquaculture Management Company filled its first export order in 2001, harvesting 18 tonnes of yellowtail amberjack destined for the United States, with 23 companies from all over the world (including Asia, Europe and United States) showing interest. This type of fish farming could turn into a major new industry for South Australia (Anonymous 2001).

Yellowtail are mainly marketed fresh, chilled or frozen at a price ranging from US$ 5-18/kg, depending on the region and the season of the year. In Italy, the average market price for greater amberjack is € 20/kg. One of the most important factors is that this fish can be sold at every size (whole, fillets or steaks and portions).

Fish quality deteriorates much faster than that of land animals. Therefore, it is vital when dealing with fish to get the product to consumers as fast as possible after harvest. Fish meat can be served as "*sashimi*" for about three days in cold storage, depending on rearing conditions and treatment after harvest. Rapid killing, bleeding, filleting, and proper packaging and refrigeration results in excellent quality yellowtail. Greater amberjack and yellowtail amberjack are more popular than Japanese amberjack because they can be kept for more than three days under refrigeration without losing their flavour, colour, and firmness. Currently, demand for them exceeds the supply (Nakada 2000).

Yellowtail commodities have also an import-export trade. Imports are small but show an increasing trend in recent years; their volume and value are shown in Figures 126 and 127, respectively. In 1999 Japan was the leading importing country (Table 75).

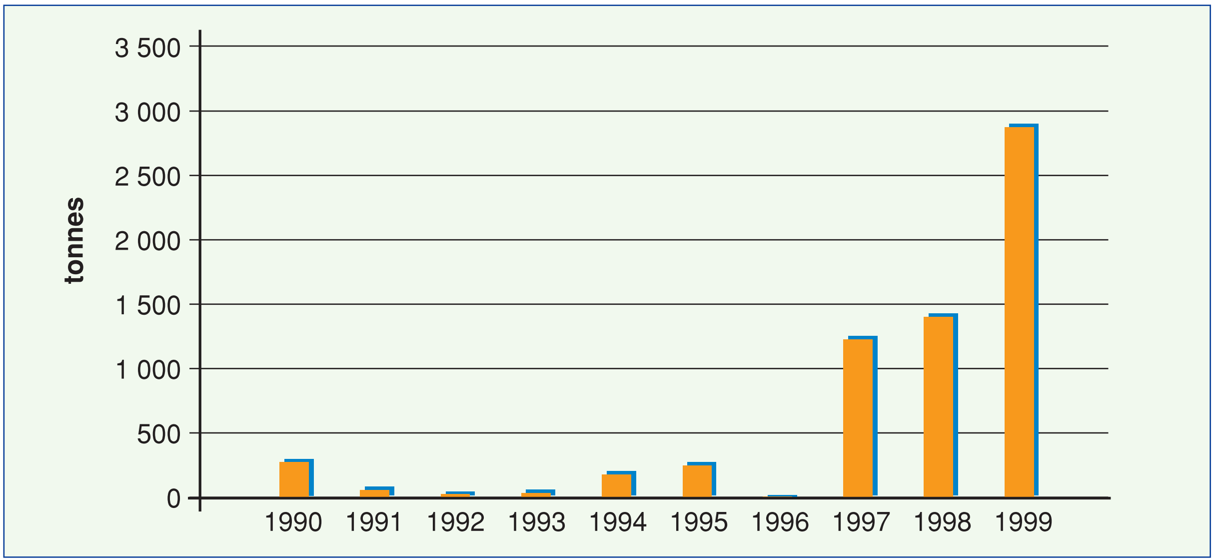


Figure 126. Trends in the total volume of imports (all countries) of yellowtail commodities, 1990-1999 (FAO 2002d)

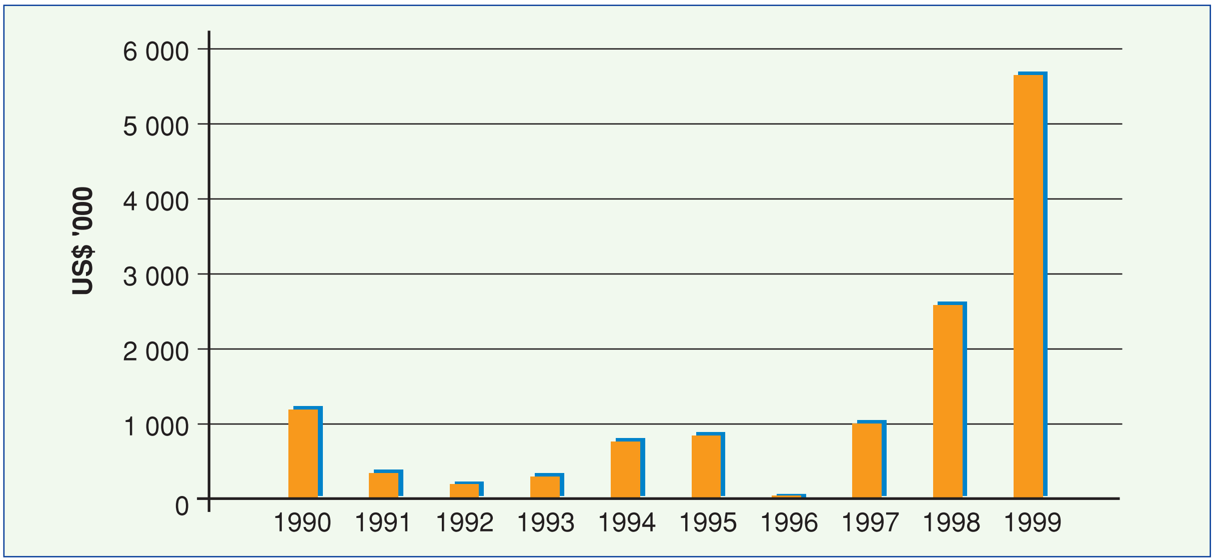


Figure 127. Trends in the total value of imports (all countries) of yellowtail commodities, 1990-1999 (FAO 2002d)

Table 75. Characteristics of the yellowtail import trade in 1999 (FAO 2002d)

Country	Commodity	Import quantity (tonnes)	Import value (US$ '000)
Japan	Yellowtail, fresh or chilled	1 908	3 478
Japan	Yellowtail, frozen	918	1 179
Poland	Yellowtail, fresh or chilled	46	990
TOTAL		**2 872**	**5 647**

There is a generally increasing trend in the total export of yellowtail (Table 76), which are mainly by the Republic of Korea. There is a very little interest in the production or trade of frozen yellowtail products. Most of yellowtail are traded fresh or chilled.

Table 76. Yellowtail export trade (quantity and value) in 1999 (FAO 2002d)

Country	Commodity	Export volume (tonnes)	Export value (US$ '000)
Korea, Republic of	Yellowtail, fresh or chilled	871	1 578
New Zealand	Yellowtail, fresh or chilled	71	270
New Zealand	Yellowtail, frozen	1	3
Poland	Yellowtail, fresh or chilled	<0.5	41
TOTAL		**943**	**1 892**

Conclusions

Japanese amberjack culture is well established in Japan and other Asian countries, and products have a good market image. However further expansion will be limited due to the supply of juveniles. Although juveniles are available from hatchery supplies, their quality is below that of wild-caught juveniles. The development of the two similar species, especially yellowtail amberjack, could see an increase in production in Japan, with other countries, notably Australia, entering the market. With the development of capture-based culture systems in the Mediterranean for tuna, there is renewed interest in greater amberjack culture in this region.

The key restrictions to increasing production are juvenile supply, the development of successful feeds and the introduction of better management practices to limit losses from "red tide" events, which themselves are probably due to poor feeding regimes. All yellowtail (*Seriola* spp.) products have the potential to be developed into many popular forms, and also into pre-prepared meals, which are becoming a major market in developed countries.

chapter 7

ENVIRONMENTAL IMPACTS

7

ENVIRONMENTAL IMPACTS

Introduction

As noted in Chapter 1, capture-based aquaculture is an overlap between fisheries and aquaculture, since it is based on the removal of "seed" from the wild stocks for subsequent on-growing in captivity using aquacultural techniques. This practice may have an impact on both the environment and the ecosystem. Although these impacts may be negligible, and the benefits to the local communities considerable, it is still necessary to understand and evaluate the potential effect on the overall ecosystem. There are many examples of ecologically-unsustainable development and the need to prevent their repetition on a global basis has been generally accepted. The problem has to be balanced with the requirement for economic development and increased food production in developing countries. Finding the balance between rational use, conservation and preservation is the logical course to optimize man's use of natural resources on a long-term basis. To assess the sustainability of capture-based aquaculture, all environmental impacts need to be considered, bearing in mind the complexity of the ecosystems involved. This chapter considers environmental impact under two general headings or steps.

The first step, which relates to fisheries, consists of the collection of the "seed" from wild resources. The effects of "seed" collection are direct or indirect and are considered in the next two sections of this chapter, on "resource removal". The direct effects consist of the fishing mortality exerted on target populations (overfishing), the impact of removing immature fish from the genetic stock, the fishing mortality sustained by non-target populations that are caught or killed along with the target species (bycatch and discards), and the physical impacts on benthic organisms and habitats (by detrimental fishing methods). Indirect effects include the impacts caused by biological interactions between species in the ecosystem (i.e. competition, predation, changes in the trophic chain), the mortality caused by lost gear (ghost fishing), and the environmental effects of dumping discards (Goñi 1998). Indirect effects have the potential to create greater impacts on aquatic ecosystem structure and function than fish removal (Hammer, Jansson and Jansson 1993; Botsford, Castilla and Peterson 1997; Helmlund and Hammer 1999). It is more difficult to characterize indirect effects because they are complex, respond to poorly understood feedback mechanisms and may occur over large areas and at a variety of time scales (Goñi 1998).

The second step, concerns the aquaculture systems used for capture-based aquaculture. These share most of the environmental aspects related to "classical" aquaculture methods. The culture of fish in cages has the potential to cause both onshore and offshore impacts on the surrounding environment, with a severity scaled to the size and the intensity of the farming operation. Such impacts include distortion of the local ecosystem; short- and long-term near-field and far-field eutrophication, chemical pollution (i.e. by xenobiotics), cross-transmission of parasites and pathogens, aesthetic deterioration in coastal areas, organic enrichment, and habitat modification, etc.

Other impacts concerning the aquaculture side of the operation are specific to capture-based aquaculture practices and include both environmental and social effects. One example of this is the towing of the cages used for the collection of live tuna at sea, which can take several weeks or months, depending on the distance between the catching location and the aquaculture site. This operation may result in conflicts with other fisheries and with shipping navigation. The effect of farming operations are considered in the section of this chapter entitled "effects of farming operations (grow-out)".

It is very clear that there are many potential environmental impacts of capture-based aquaculture. The problems associated with the removal of "seed" from wild stocks are very difficult to quantify or accurately assess, and the concerns of the fisheries sector must be addressed. However, the benefits and potential value-added inputs to a fishery need to be balanced against the negative effects.

Resource removal – direct effects

The direct effects of the collection of wild "seed" for capture-based aquaculture are reviewed in this section of the report.

Overfishing

The main reason why species are chosen for capture-based aquaculture is their high market value. As a result of their value, most of these resources are already heavily exploited by commercial fisheries. Since the basis of capture-based aquaculture is the collection of "seed" from the wild stocks, this activity may increase the fishing effort on the target species. A particular danger arises for populations that are economically valuable but have low reproductive capacities because they mature at a large size.

FAO assessments of the various world fish stocks classify them in a range of categories from "under-exploited" to "overfished". According to Hall (1999), overfishing can be divided into two types, recruitment overfishing and growth overfishing.

Recruitment overfishing occurs when a stock is depleted to a level where there is an unacceptable risk that the remaining adults will be insufficient to produce enough offspring to maintain the stock. This situation is most likely to occur in pelagic species where the individuals often form dense aggregations that can be easily detected, so that catches and catch rates can remain high even when the stock is severely depleted (Hall 1999). Additionally, many pelagic species are prone to dramatic natural fluctuations in recruitment success (e.g. the "*anchoveta*" in Peru and the herring fisheries in the North Atlantic, which both occur without warning).

The other type of overfishing is termed "growth overfishing", which describes a state where fish are harvested at the wrong time in their life cycle. The extremes are the removal of a few larger older fish, or the capture of many small young fish. In between there is an optimal age at which the product of numbers and body size is maximal (Hall 1999).

Despite apparently substantial efforts to manage fisheries worldwide, there has been an almost universal failure to prevent the decline of fish stocks and the deterioration of the marine environment. Between 73-75% of the fish stocks globally offer no possibilities for increasing catches (FAO 2000).

The difficulties facing fisheries management in reducing fishing effort before the commercial extinction of the target stocks occur are immense. The characteristics of the life history of each species determines the level of fishing effort that will risk the survival of an exploited stock. Those characterized by short-life spans, rapid population growth and high reproductive output (R-selected species) respond rapidly to fishing and can cope with relatively high levels of mortality at young ages. Conversely, species with low natural mortality that allocate more energy to individual growth through competitive fitness than to reproduction (K-selected species), will support relatively low rates of fishing mortality and at older ages (Goñi 1998).

Accurate assessment of the effects of overexploitation on a target population is not a simple task. In most cases this is due to the difficulty in separating natural and fishing-related mortality, and to the lack of stock assessment studies prior to the onset of exploitation. Where a direct link between stock collapse and over-exploitation has been established, natural changes (such as unusual hydrographical conditions) have also been seen to exist (Goñi 1998; Masuda and Tsukamoto 1999).

The selected species that are considered in this report exhibit late reproduction, large size at reproduction, long-life spans, and form large spawning aggregations. This makes them vulnerable to overexploitation. In fact, the impact of intensive fishing is exacerbated by the K-selected life strategies of these genera and their tendencies to form predictable spawning aggregations. This may be critically important for population maintenance and the genetic diversity of the breeding stocks.

Heavy impacts on spawning aggregations are generally undesirable, and every attempt should be made to protect these brief, but important phases of the life cycle of these species from excessive disruption or exploitation. It is also essential to know how long the aggregations last, whether fish spawn throughout the entire period, and whether the same fish return repeatedly to the same site. Additional knowledge concerning the distance individuals travel to each aggregation site, and the proportion of any particular population involved in each aggregation, would facilitate management.

At the present time, none of the life cycles of the selected species is completely understood, and the biology of the species could cause more difficulties for stock evaluation. For an example, the removal of fingerlings from heavily fished adult populations may be an important factor contributing to the population decline of species such as the Hong Kong grouper *E. akaara* (Morris, Roberts and Hawkins 2000). This is likely to be significant because they spawn in limited areas throughout their geographic range. Sometimes this may simply reflect an area that is heavily exploited in general, but the possibility cannot be ruled out that some populations may be partially or fully self-recruiting and depend entirely on one or several aggregations (Rhodes and Sadovy 2002). Capture-based aquaculture seems to influence the status of some local grouper populations due to the "seed" collection for aquaculture practices. According to Sadovy (2000), capture-based grouper "seed" availability has declined in many areas of SE Asia, which may be in part be attributable to overfishing.

Carangid fish such as the greater amberjack have been heavily exploited because they form schools as an ecologically anti-predatory behaviour. Since 1993 (Andaloro 1993; Mazzola *et al.* 1993), some published fishery statistical data on the greater amberjack (*S. dumerili*) have indicated an over-exploitation of the juvenile classes in some areas of the South Mediterranean Sea. The availability of greater amberjack juveniles for capture-based aquaculture today comprizes a bottleneck for the development of this activity in Mediterranean countries. On the other hand, the status of the greater amberjack in the Gulf of Mexico has been estimated to be not overfished (NMFS 1998). Defining a species as overfished is difficult when several factors occur at the same time; this is the case for the Japanese amberjack (*S. quinqueradiata*) in its Pacific sub-population. Terauchi *et al.* (1991) observed a declining trend in adult fish stocks. This was probably due to the collection of larvae ("*mojako*"), which affected recruitment to the adult stock, coupled with a short-term decline due to an environmental factor (an abnormally low water temperature in the Pacific coastal sea area of Japan observed that year).

Most tuna stocks in temperate or tropical waters are under heavy pressure and are intensively or fully exploited. Some stocks are already overfished. Biological overfishing has been avoided on many stocks because of economic constraints and by transferring excess fishing capacity to other areas and oceans (South Pacific, Indian Ocean). By fishing further offshore on domes and thermocline fronts, the potential for increasing the exploitable biomass has reduced effort on more easily accessible, but less prolific stocks. After declines in the populations of bluefin tunas (northern and southern populations) were recorded, these stocks have been managed by regional bodies. The Convention for the Conservation of Southern Bluefin Tuna (CCSBT) was negotiated in 1994 in response to dramatic population declines. In the past, massive overfishing probably reduced the ability of the species to naturally replace itself and maintain healthy population levels (Buck 1995), so that today it is still considered an overfished resource. ICCAT (the International Commission for the Conservation of Atlantic Tunas) has defined two management units, West Atlantic tuna and East Atlantic tuna populations. Tudela (2002b) states that the western stock is overexploited and notes that the assessment of the East Atlantic bluefin tuna stock by ICCAT published in 1998 indicated that there had been a strong decline in the spawning stock biomass since 1993, as well as an increase in fishing mortality rates. The spawning biomass was estimated to be less than 20% of the 1970 level, and projections predicted a high probability of collapse within the following few years. The intense fishing pressure on small tunas seems to be contributing to overfishing and is reducing the potential long-term yield from the resource (Tudela 2002a,b,c). Today it is still difficult to evaluate the stock owing to lack of scientific data. It has been shown that it is difficult to detect overfishing or stock depletion risks in bluefin tuna, as spawning stocks and yields display conspicuous long-term fluctuations. This is the result of a combination of year-to-year variations in recruitment and a long life span, as Fromentin and Fonteneau (2001) have shown using a mathematical model.

There has been a general reduction of the catches of glass eels of the European eel (*A. anguilla*) but recent studies have show that there is no actual decline in the total fishery yields along the Swedish west coast (Svedäng 1999). Globally, the annual catch of glass eels of all species has gradually decreased over the past 25 years (Tanaka 2001) and a shortage of “seed” fish has become a very serious problem for eel capture-based aquaculture.

Recruitment success

Sensible exploitation of a fish stock requires management through legal and social instruments that in some way limit access to the resource. The fundamental biological aim for managing fisheries on a sustainable basis is that the catch rates should be balanced by recruitment. The problem is that for most stocks, recruitment cannot be simply predicted. While biological objectives have been the focus for fisheries biologists (and the sustainability of stocks is clearly a primary consideration), economic and social aspects of fisheries management also have profound effects on the choice of management regime, and the rigour with which it is imposed (Hall 1999).

For the species used in capture-based aquaculture, the problem of predicting recruitment is by far the most difficult facing fisheries biologists, who cannot be held solely responsible for the failure to manage fisheries successfully. Sound scientific advice is often not implemented because political and economic interests overturn it.

In pelagic spawning fishes such as groupers, where eggs are released into the water column to drift within surface currents, early natural mortality rates must be extremely high between egg production and settlement (when young fish change from their planktonic to their benthic phase) (Sadovy and Pet 1998). Estimates suggest that although each female grouper is capable of producing millions of eggs, only two young from each spawn will survive to adulthood under stable population conditions. What is not known is where the bulk of this early natural mortality occurs, and what the causes of this mortality are. If natural mortality remains high for some time after settlement, then the removal of young juveniles for capture-based aquaculture may have little impact on adult stocks, because most juveniles taken would otherwise perish due to natural causes. However, if early natural mortality rates have dropped to low levels prior to juvenile capture, then fishing mortality will represent an important source of total mortality (which is the sum of fishing mortality plus natural mortality).

Natural mortality drops rapidly during the early post-settlement period in tropical reef fish, i.e. several weeks or months following settlement. This strongly suggests that post-settlement mortality drops within a few weeks or months after settlement on a reef across a wide range of species and, moreover, that any harvest after this early period can negatively influence subsequent stock size (Sadovy and Pet 1998). Specimens taken for culture may be up to one year old at capture, and therefore many are probably caught well beyond the early weeks or months post-settlement. If this is the case, then fishing mortality represents a substantial proportion of total mortality and the fishery should be managed to avoid overfishing.

Fishermen (Figure 128) and researchers in the region agree that they see postlarvae in much greater numbers than grouper fry or fingerlings. This suggests that, as with the reef fish discussed above, there is considerable natural mortality among the postlarvae. Harvesting of postlarvae would thus have a lower impact on future adult populations than the harvesting of fry or fingerlings (Johannes and Ogburn 1999). However, the on-growing of a species in net cages intensifies fry collection in many areas and tends to reduce recruitment (Ahmad 1998).

Bycatch and discards

Most of the collection of “seed” material for capture-based aquaculture is carried out with traditional fishing gear. The aim for capture-based aquaculture is obviously to collect live fish for on-growing; the fishing technique selected should therefore be selective for the species and size of “seed” required for the aquaculture system. However, no gear is known to be one hundred percent selective for a given species or size range of individuals. Most gear and methods have some selectivity; their ability to select targets can be altered through modifications to design and operation. The catch in many fisheries thus consists of a mixture of target and non-target species. What does or does not comprize targets depends to a large extent on the market, and whether there are regulations in place prohibiting the capture of certain species or sizes of target organisms. Non-target species are often referred to as bycatch, a concept which is defined differently by numerous scientific bodies.

Hall (1996) defined bycatch as “that part of the capture that is discarded at sea, dead (or injured to an extent that death is the result)”. The word “capture”, in turn, means all that is taken in the gear. The capture can be divided into three components: 1) the “catch”, which is the portion retained for its economic value; 2) the “bycatch”, which is the portion discarded at sea already dead, and 3) the “release”, the portion released alive (Hall *et al.* 2000). The main reasons for discarding fishes (dead or alive), are as follows: the fish caught are the wrong species, size or sex, or are damaged; the fish are incompatible with the rest of the catch (from the point of view of storage); the fish are poisonous or spoil rapidly; there is a lack of space on board; “high grading”[1] ; quotas have been reached; or the catch was of a prohibited species, in a prohibited season or fishing ground, or achieved with prohibited gear. Unfortunately, some of the gears used in the capture of species for capture-based aquaculture species can cause an incidental catch of non-target species (bycatch) and can collect undesirable sizes of target species.

1 Special cases of bycatch that are “high-grading” exist: these comprize the discard of a marketable species in order to retain the same species at a larger size and price, or to retain another species of higher value.

Figure 128. Fishermen repairing their fishing gear in the Philippines (Source: FAO)

The amount of the bycatch depends on the area, the period (season), and on the selectivity of the fishing gear. The bycatch issue is important for capture-based aquaculture species as it is one of the most significant of those affecting fishery management today. Different fishing techniques can lead to distinct types and rates of bycatch such as juvenile fish, benthic animals, marine mammals, marine birds, and vulnerable or endangered species, etc., that are often discarded dead. While bycatch and discard problems are usually measured as the potential loss of human food, the increased risk to a particularly vulnerable or endangered species (e.g. small cetaceans, turtles) is also significant. Bycatch can also affect biodiversity throughout impacts on top predators. For economists, its existence generates additional costs without affecting revenues, and may hinder long-term profitability. For fishermen, it causes conflicts among fisheries, gives them a bad public image, generates regulations and limitations on the use of resources, and has negative effects on the resources harvested through the mortality of juveniles and undersized individuals of the target species before they reach the optimum size. This problem must be addressed by scientists, fishery managers and members of the fishery industry. Although only a few fisheries include bycatches of the target species in their stock assessment, bycatch management will be an integral part of most future ecosystem management schemes (Hall *et al.* 2000). The total global discard (considering all the fisheries) is difficult to estimate. One assessment of the level of discards gave an estimate of 27 million tonnes in 1995 (FAO 1997c).

Besides the bycatches of fish (Figure 129), other animals may incidentally be captured with fishing gears (e.g. various species of whales, turtles and seabirds); although the level of the bycatches of such organisms seldom constitutes a threat to their population size, public concern makes it necessary to reduce them.

The level of bycatch associated with the collection of wild “seed” for capture-based aquaculture is not well documented. The same gear could cause different bycatch impacts depending on the area in which it is used. For example, catching bluefin tuna for capture-based aquaculture with the purse seining system in the Mediterranean is very efficient and does not entail high bycatches of cetaceans. This is not the case in other regions, such as purse seining in the Eastern Pacific. The best known example is the tuna-dolphin problem: incidental mortality of dolphins in tuna purse-seine fisheries in the Pacific Ocean during the 1960s was the first bycatch problem that received public attention. After the Marine Mammal Protection Act (MMPA) was introduced in 1972 (Gosliner 1999), dolphin mortality decreased from 133 000 in 1986 to only 1 877 in 1998 (Hall, Alverson and Metuzals 2000).

Improved selectivity can be achieved by modifying the gear design and/or operation, and by using alternative fishing gears. The capture of dolphins in the purse seine fishery for tuna has been reduced to an insignificant level by using a combination of technical changes, rescue techniques, the education of fishermen, and management actions. Experimental research is still going on in order to understand the potential danger represented by the "pinger", an acoustic device that may disturb the dolphins.

Some of the capture-based aquaculture species are collected using floating objects or Fish Aggregating Devices (FADs); pelagic fish are often found in association with FADs as well as other animals (mammals, fish). Other natural structures (underwater mountains, etc.), artificial structures (wrecks or artificial reefs), or specially constructed FADs (like those used in Mauritius for game fishing or the "*cheema*" used in the Maltese "*lampuka*" fishery) are also effective. The reasons for this behaviour are still poorly understood, yet it is believed that by providing a substratum, smaller "feed" fish are initially attracted, which in turn attract the larger commercially valuable species.

Yellowtails are known to associate with FADs, and this is especially true for the greater amberjack (*Seriola dumerili*) and the Japanese amberjack (*Seriola quinqueradiata*). Since the 1980s tuna fishermen have been constructing and deploying artificial FADs, sometimes fitted with transmitter beacons to aid location. These electronically equipped FADs can the be deployed using new spatial strategies (Hallier 1995), and some also have echo-sounders that transmit information about the aggregated biomass by radio (Josse *et al.* 1999).

Harvesting fish associated with floating objects might threaten the pelagic ecosystem, due to various negative effects, such as an increased catch rate of juveniles or pre-reproductive animals, or an excessive mortality of non-targeted species (Hall 1998). A better understanding of these associations is therefore required to design and implement appropriate sustainable management procedures (Fréon and Dagorn 2000).

Other gears and various fishing methods used for catching of "seed" for capture-based aquaculture operations (e.g. grouper) result in a high level of bycatch. For example, research carried out in Indonesia demonstrated that a very high percentage of the total catch captured in artificial reefs (called "*gangos*" in the Philippines) were non-target species, and that this method of harvesting can lead to a high bycatch mortality if not carefully handled (Mous *et al.* 1999). For many other gears used for grouper collection (e.g. fyke nets, scissor nets), bycatches during certain periods can be high. The bycatch comprizes a variety of fish sizes and species that are often thrown back at sea. The exception is in the densely populated areas of many developing countries, where the bycatch has a commercial value and is largely used for local consumption. In SE Asia this has serious implications, and the impact of "seed" fish for on-growing on local foodfish resources cannot be ignored. For example, the bycatch of small juvenile rabbit-fish (*Siganus* spp.) is often high and represents a double loss, because in the same area the larger sizes of this species constitute a favoured food fish (Sadovy 2000).

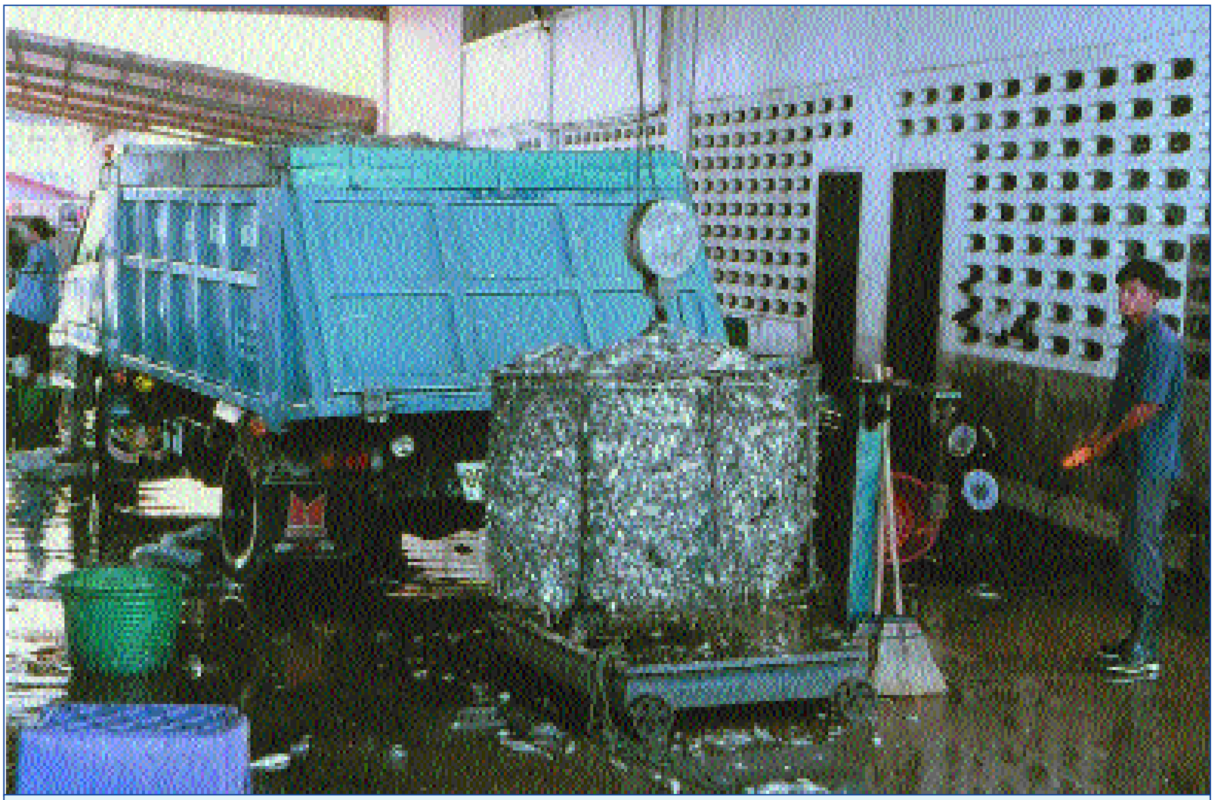


Figure 129. Bycatch being delivered for fish feed in Thailand (Photo: FIIU-FI-FAO)

The use of trawls for eel fishing leads to a substantial bycatch. Due to their small mesh size, the trawl net affects many juvenile fish and up to 99% of the catch consists of species different from the target species, the eels (Hahlbeck 1994). The fyke net is another catch method that captures non-target species (Naismith and Knight 1994).

Direct physical disturbance and habitat destruction

Capture fisheries not only reduce the abundance of targeted stocks, but can have significant effects on the overall ecosystem and food chain, with consequences in other ecological and fishery-dependent systems, including those of mammals (Dayton *et al.* 1995). In addition, many nearshore ecosystems are substantially altered through habitat destruction caused by particular fishing methods.

The use of sodium cyanide, widely employed in the Philippines to catch groupers for capture-based aquaculture, is contributing to the destruction of coral reefs (Goñi 1998). This method not only causes direct damage to the habitat but also has collateral effects, including the death of non-target species of fish and invertebrates (Mous *et al.* 2000), as well as poor quality "seed". The effects of poison on fish can be expected to be rather non-specific and alterations in the fish community structure and ecosystem appear likely.

Other gears used in Southeast Asia for the collection of "seed" for capture-based farmed species can be detrimental to near-shore habitats which are important nursery areas for many species. The use of scoop nets can cause significant impacts on the seabed and on benthic communities (Sadovy 2000). Benthic organisms are crushed, buried, or exposed to predators, and clouds of sediments arise. Alterations to the seabed biogeochemistry are also possible. Development management strategies that are designed to protect habitats are now established, and the use of scoop nets in several regions has now been banned or is regulated to reduce potential impacts.

Several organizations (e.g. the International Marine Life Alliance and the Nature Conservancy) have alerted coastal communities to the threat posed by destructive fishing, and "sustainable mariculture practices" and "best management practices" are rewarded at all points along the supply chain with increased prices and better market acceptance of products (Sadovy 2000; Hair, Bell and Doherty 2002).

Resource removal - indirect effects

The indirect effects of collecting "seed" for capture-based aquaculture include the impact on biological interactions between species in the ecosystem (i.e. competition, predation, changes in the trophic chain), mortality caused by lost gear (ghost fishing), and the environmental effects of dumping discards. The removal of fish with key characteristics and functions in a specific ecosystem may result in loss of resilience and a change from one equilibrium state to another. Fisheries managers are becoming increasingly aware that the impacts of fishing and overfishing can spread through the entire food chain because of changes in competition and predation patterns. It is very difficult to separate natural and man-induced causes for the changes observed at different levels of the ecosystem. Evaluating impacts on fisheries and on communities is also difficult because there are normally no control sites where fishing has not occurred (Goñi 1998).

Fishing for capture-based aquaculture species can alter the structure of marine communities by selective removal of some species and by changing the physical support for the communities. Biomass replacement, in which a dominant species is driven to low levels and is substituted by another species, can occur as a result of fishing and can cause ripple effects on other components of the ecosystem. While biomass flips in species abundance in a pelagic marine ecosystem appear to be caused by density-independent environmental changes (affecting nutrient entrainment, primary production, and recruitment success), dominance flips in several continental shelf marine ecosystems are attributed to density-dependent predation, which includes fishing (Goñi 1998). Hughes (1994) showed how this recovery mechanism has been hindered on Jamaican coral reefs by human activity. Since the 1950s, the Jamaican coral reefs have been chronically overfished to such an extent that sharks, snappers, jacks, triggerfish, groupers, and a number of other target species have declined markedly. The loss of herbivorous and predatory fish species has reduced total fish biomass and altered the taxonomic composition of the fish community. However, the ecological effects of this decrease in biodiversity were not realized for several decades, as the reef appeared to be healthy with large coral cover and high benthic diversity. This was largely due to the high abundance of one grazing echinoid *Diadema antillarum*, which held the growth of algae on the reef in check. With the decline of fish predators and competitors, the abundance of *Diadema* increased.

Other indirect effects have been caused by discards and offal; the large quantities that can result from the processing of fish at sea and from discards may cause changes in the structure and biodiversity of marine communities. Assessments of these effects requires knowledge about the fate of the discards and offal that, until recently, has been largely neglected in studies of fishery-ecosystem interactions (Goñi 1998).

Fishing procedures also pollute the environment through the accidental loss of fishing gear and/or by the dumping or abandoning of gear that may continue to capture and entangle animals. The impact of such "ghost fishing gear" is basically unknown but there are indications that the problem is increasing to significant proportions (Goñi 1998).

Though there has been some work on the indirect effects of fishery activities in general, only a few specific impact studies related to the capture of wild "seed" for capture-based aquaculture species are documented. For example, Sadovy (2000) showed that some grouper seed collection methods have significant impact on the long term status of the stock. The authors of this report consider it unlikely that these fishing methods have a greater effect on fish than other types of fisheries.

Effects of farming operations (grow-out)

Capture-based aquaculture implies the on-growing of selected species in captivity using "traditional" aquaculture practices. Typically the capture-based farmed species are enclosed in a controlled system, such as ponds or cages. In these they can be raised under suitable conditions, sheltered from predators and competitors, fed, and sometimes treated with medicaments to control diseases. The fish are confined at high densities and ideally supplied with all nutritional requirements. Thus, the more intensive the operation, the larger volume of wastes generated and potential impact on the local environment, and the greater the potential for disease.

Generally, intensive fish farming in cages generates a large amount of organic waste in the form of unconsumed feed, and faecal and excretory matter. This results in localized sediment build-up with its attendant risks from self-pollution and disease, which may threaten the operations own sustainability. The particulate waste matter, originating from a single source, can accumulate in the sediments below or close to the farm, causing considerable organic and nutrient enrichment that may adversely affect benthic communities. Major effects can be observed on the seabed and, to a lesser extent, on water quality. Careful site selection is critical for a successful, sustainable operation of all fish farms; special care is required in the case of marine aquaculture (Figure 130).

Figure 130. Philippines capture-based aquaculture (Photo: S. Fazi. Coastal Resource Management and Sustainable Tourism in Ulugan Bay Project implemented by (UNESCO/CSI/UNDP/Puerto Princesa City Government 2001)

Selecting a poor site may result in oxygen depletion in the bottom water, leading to the development of anoxic conditions in the sediment and the production of toxic gases such as hydrogen sulphide. These phenomena will adversely affect benthic organisms as well as the lower portion of the cages where the water is shallow. Furthermore, a reduction in dissolved oxygen level and an increase in Biochemical Oxygen Demand (BOD) and nutrients will occur in the water column around a fish farm, especially where the flushing rate and water exchange levels are too low for the biomass being raised. Other effects will also be observed, including an increase in suspended solids, chlorophyll and phaeopigment concentration, etc.

Usually, most fish farms have limited and localized environmental impacts associated with waste release; these are restricted to those areas in the immediate vicinity of the farm. In shallow waters, or in aquatic ecosystems with a poor water renewal rate, localized eutrophication around farms is possible. Polluted waters may result in fish disease and the mass mortality of cultured fish. The severity of environmental impacts depends upon the relationship between the intensity of fish culture operations and the water circulation/depth at the culture site (e.g. stocking density, feed input and the characteristics of the site). The level of sustainable production at any particular site is therefore a balance between the environmental waste loading (nutrient and organic matter) caused by the farm, and the renewal of the water at the site which prevents a build-up or significant change in the existing local environmental conditions. The use of mass balance equations and management mitigation measures can prevent this occurring. The most obvious changes caused by poorly located intensive marine culture systems for carnivorous fish in cages, are those to the local environment. These impacts, mainly on the benthos, may cause long term changes at sites in relatively quiescent waters, that may persist for many years after culture activity has ceased (Black 2001). Wu (1995) suggested that the degree of impact from the effluent wastes of cage aquaculture is dependent on the species, culture method and feed type, and on the nature of the receiving environment in terms of physics, chemistry and biology.

In the Mediterranean, the capture-based aquaculture of tuna is relatively new and so little is known about its environmental impact on the marine ecosystem. Tuna “farming”, among other activities, has been the target of criticism from environmental and other pressure groups due to the perceived impact of the industry on the environment (for an example of such views, see Tudela 2002a). A system that minimizes its impact, which removes uneaten food and consists of using a collecting net similar to that used in salmon farming, has proven to be successful (Agius 2002).

On the contrary, the impact of grouper capture-based aquaculture is clear, since there are lot of problems concerning water quality in the production areas (as also is the case for the yellowtails cultured in Japan). For example, water quality conditions are particularly poor in Hong Kong, parts of China, the Straits of Johore Bahru (Singapore/Malaysia) and the Philippines; in these locations fish densities are poorly managed, trash fish use is extensive, and there are problems with water contamination or low dissolved oxygen levels because of poor cage positioning. In the early 1990s, grouper production in Hong Kong was about 3 000 tonnes a year; in the last few years production has dropped to 1 000 tonnes a year due to several production and environmental problems (Sadovy 2000). There is an increasing interest in monitoring the environmental degradation from fish farming; thus, many countries have introduced tighter controls. Since 1999, Japan has introduced new legislation for the monitoring of sediment and water quality in fish farming areas, in order to assess sustainability (Pawar *et al.* 2001).

Advanced research efforts aimed at developing technical improvements in the systems used for eel farming are increasing, especially with regard to water quality, which has been a traditional problem in this type of culture (Gatta, Romagnoli and Venzi 2000). The problems to be addressed vary, depending on the species, area, stocking density, environmental capacity of the aquatic bodies, etc.

For the sake of simplicity, we have divided the main environmental effects of capture-based aquaculture into the following categories: feeding, organic pollution and eutrophication, effects of chemical use, algal blooms, benthos modification, and other interactions.

Feeding

Feeding in the capture-based aquaculture of most target species is mainly based on the use of trash fish, due to the inability of some of them to accept prepared diets. The use of trash fish has several disadvantages. There is a heavy dependency on the availability of locally caught fish for the production of the greater amberjack (*S. dumerili*) in Japan. The feeding of trash fish to densely cultured fish frequently results in deterioration of the environmental quality of receiving waters, leading to eutrophication and various fish diseases (Watanabe *et al.* 1991). Trash fish also have variable nutritional values and the potential for contamination due to being stored in poor hygienic conditions. In addition, its preparation (Figure 131) and storage require high labour inputs and specialized storage facilities (Shimeno 1991). Semi-moist diets are often prepared for feeding the greater amberjack in Japan through extruders mounted on board feeding boats; the ingredients comprise a mixture of "trash" fish with a premix of dry ingredients (M. New, pers. comm. 2003). Such diets are transferred to the cages in a flow of water. Extruded semi-moist pellets are also used (Figure 132). A photo of the feed delivery system to the cages is shown in Figure 139 in the following chapter of this report.

Worldwide, there is a general tendency to try to adopt the use of formulated diets; however, the use of trash fish still remains the norm in some areas, owing to conservative attitudes and/or economic reasons. When fish can be weaned onto a specialized prepared diet that replicates the normal nutritional intake, there is good evidence that they will perform much better than those fed on trash fish (Bell 1998). The existence of a link between high levels of feed wastage and the use of trash fish is still controversial, but current opinion favours the use of pellets (e.g. Black 2001; Chu 1999).

Figure 131. Trash fish used to feed capture-based farmed species in Asia (Source: NACA)

Figure 132. Dissection, showing pellets used for feeding capture-based farmed yellowtails
(Photo: M. Nakada)

Waste feed from cage farming operations is always a problem. However, the particle size of that generated from the use of trash fish is much smaller than from prepared diets, leading to a wider dispersion and greater impact upon a larger area. In Hong Kong, marine fish culture activities are responsible for 3% of total BOD, 3% of total nitrogen loading, and 20% of total solid loading from domestic and industrial sewage discharges into the coastal waters. Of these cumulative pollution loadings 65% were derived from feed wastage alone (Chu 1999); trash fish is extensively used as feed in this location.

In some capture-based aquaculture (e.g. the culture of eels), fishmeal and fish oil are the key constituents of prepared feeds for intensive production (Tacon and Forster 2000). According to Black (2001) it requires 2 to 5 kg of captured fish to produce 1 kg of fish fed with a fishmeal based diet. There is a movement towards the substitution of fishmeal and fish oil by vegetable sources, in view of the limited supplies of marine feed ingredients (Goldbourg, Elliott and Naylor 2001; New and Wijkström 2002).

In terms of farm activities, feeding a formulated diet is easier than using trash fish, which demands more effort (buying, transporting, storage, thawing and chopping). However, when economic analyses are considered, feeding with trash fish may prove cheaper (Table 77), a factor that leads to understandable resistance to change, particularly amongst the operators of small grouper farms in SE Asia, for example (M. New, pers. comm. 2003).

Table 77. Comparative analysis of annual costs and returns per hectare of wild orange-spotted groupers *(Epinephelus coioides)* fed on alternative diets for 5 months in grow out ponds (Bombeo-Tuburan *et al.* 2001, modified)

Feed	Costs (US$)	Income (US$)	ROI (%)	Payback (years)
Trash fish	1 103	7 232	155	0.4
Formulated diet	2 259	1 233	21	3.1

As a general rule, total dry diet costs should not exceed 25% of the farm-gate value of the cultured species (Tacon 1995). The formulated diet alone in the study of Bombeo-Tuburan *et al.* (2001) accounted for 39% of the total cost; thus from an economic viewpoint the formulated diet in this study was not suitable.

A good feed management system is essential for bluefin tuna farming. In the Murcia region of Spain, where the leading Mediterranean companies are located, the key environmental impacts are related to feeding and excretion. Impact due to feeding occurs because fish have a very poor FCR (up to 30:1). This depends on the water temperatures prevailing during the culture period. From this data it can be expected that there is a high degree of biological loading from waste materials (Belmonte Ríos 2002). In a study in Croatia, approximately 6 200 tunas (average size 11.2 kg) were stocked in one cage, and fed daily at 5.08% of biomass, with a mixture mainly consisting (87.9%) of herrings (*Clupea harengus* L.), *Sardina pilchardus* (6.7%) and cephalopods (5.4%) (Katavic, Vicina and Franicevic 2003a).

In Port Lincoln, South Australia, farmed southern bluefin tuna are fed bait fish twice per day, six days per week. Feeding is generally done by placing frozen blocks of bait fish in a mesh cage within each pontoon (see Chapter 5, Figure 96). In 2001, 20 different species of bait fish were used (45 000 tonnes), which were sourced locally and overseas; FCRs averaged about 10-15:1 (Clarke 2002). Poor FCR and the use of baitfish in capture-based tuna farming are major problems. Research is currently under way to develop manufactured feeds to replace this type of feeding. The demand from the tuna industry is creating increased fishing pressure on small pelagic fish stocks and some of these fisheries (e.g. anchovy), being poorly regulated, are showing signs of becoming depleted (Tudela 2002b).

Organic pollution and eutrophication

Most capture-based aquaculture is undertaken in cages, suspended in more or less open waters. Cage structures are relatively cheap, when compared with equivalent land-based facilities, and their use avoids the need for the expensive pumping of water, oxygenation and the removal of waste products. Water exchange and oxygenation are provided by the natural circulation of water through the cage system, as long as the cage is sited in a good open position. In Malta, for example, all tuna cages must be moored well away from the coast to avoid pollution risks to coastal zones. Marine coastal water quality is affected by various human activities (Figure 133) that cause discharges of organic matter, nutrients and other pollutants. The culture of fish in cages can contribute to the production of waste, which may stimulate and distort productivity and alter the abiotic and biotic characteristics of the ecosystem.

Figure 133. An example of poor water quality due to human impact (Photo: C. Silvestri)

Waste products from cage culture have a variety of sources: directly excreted, dissolved from feed and faecal particles, or released from particles that have been deposited on the seabed around the cages. Lipids originating from the diets used may form a film on the water surface, which is often observed around cages after feeding (Black 2001). The waste released from fish farms causes nutrient enrichment, the nutrients principally being carbon, nitrogen, phosphorus and silicon compounds. It is estimated that a large proportion of the phosphorus (85%), carbon (80-88%) and nitrogen (52-95%) compounds introduced into a marine fin fish culture system as feed may be lost to the environment as feed wastage, fish excretion, faeces production and respiration (Wu 1995). Feed wastage and excreted nitrogen can be significantly reduced when trash fish is replaced by pelleted feeds. Consequently, the use of trash fish is being regulated in some countries. Its use is banned in Denmark, where fish farms have to use formulated feeds (Chu 1999).

Results from various studies have shown that about 23% of the carbon, 21% of the nitrogen and 53% of the phosphorus from feed input may be accumulated in the bottom sediments, but that the significant impact is normally limited to an area within 1 km of the farm (Wu 1995). Organic matter accumulated on the seabed may lead to the development of an anoxic layer and reducing conditions in sediments, leading to the production of toxic gases (e.g. ammonia, methane and hydrogen sulphide). The toxicity of ammonia to marine life depends on pH, salinity and water temperature and the ability of the ammonia compounds to be lost to the air. The release of nitrate, nitrite and phosphorus may contribute to conditions that result in phytoplankton blooms. The majority of the nitrogen that is lost (50-60%) is in the dissolved form, directly from fish or by benthic fluxes from solid wastes beneath the cages; nitrogen losses from the fish are dependent on temperature and on dietary protein content (Buttle, Uglow and Cowx 1996).

Nitrogen is likely to be the limiting nutrient for phytoplankton growth in marine waters, while phosphorus is the limiting element for plant growth in fresh and brackish waters (Black 2001).

A nitrogen budget for the areolate grouper (*Epinephelus areolatus*) cultured under both laboratory and cage conditions has been reported (Leung *et al.* 1999). These workers attempted to balance the following equation:

$$C=G+M+E+F$$

where each term relates to a mass of nitrogen, and C is consumption, G is nitrogen retained for growth, M represents losses from mortality, E is excretory losses and F is losses through faeces. For a fish farm, the budget is represented by:

$$C=I-W$$

where I is the total input to the farm and W is the food wasted. Using a variety of techniques, Leung *et al.* (1999) were able to quantify each of these terms either by direct measurement or by difference. Figure 134 shows the budget derived for the cage farming of this species using trash fish as feed.

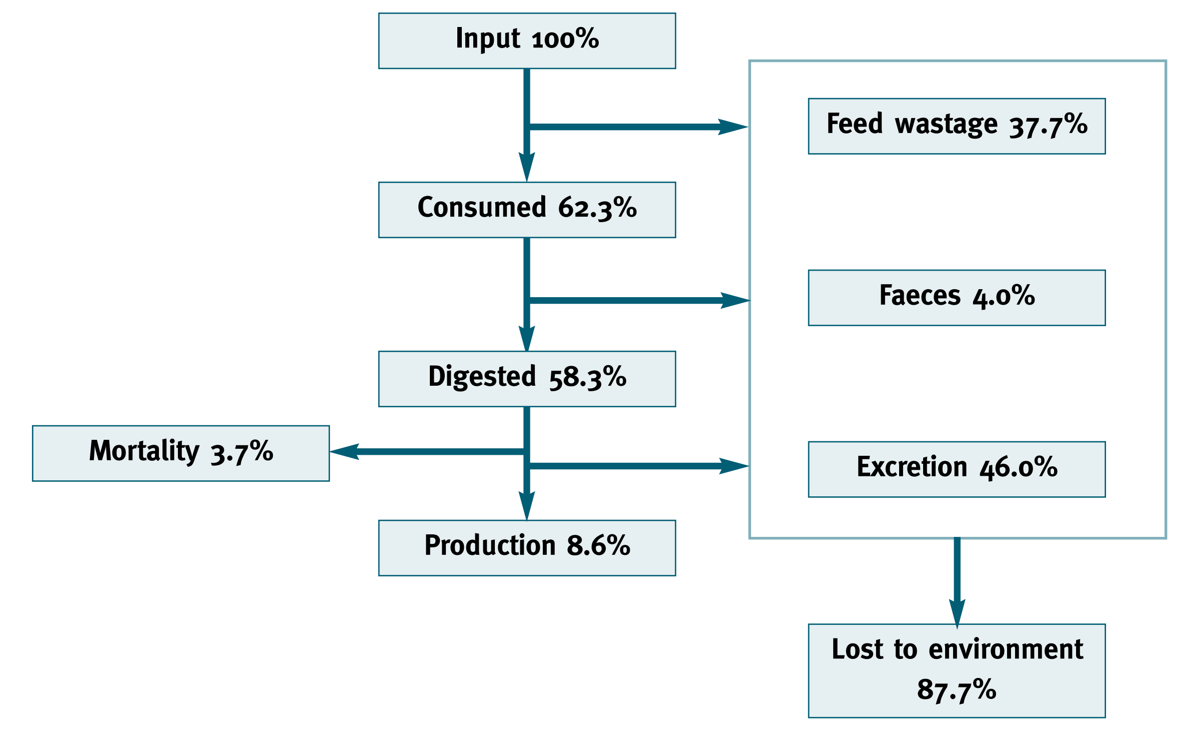


Figure 134. Nitrogen budget for areolate groupers *(Ephinephelus areolatus)* in cage culture (derived from Leung *et al.* 1999)

As shown in Figure 134, excretion of ammonia was the greatest contributor to nitrogen loss, followed by feed wastage, with faecal nitrogen loss being relatively unimportant. The nitrogen loss from this subtropical species fed trash fish is around three times greater than that for temperate species fed formulated diets (Leung, Chu and Wu 1999). Trash fish diets are inherently wasteful, as a consequence of their high nitrogen content and their tendency to break up and shed small unconsumed particles during feeding, and are thus major contributors to water quality degradation. Studies to assess the bio-energetic nutrient outputs from bluefin tuna capture-based aquaculture are in progress (Aguado and García 2003). The budget for silicon compounds is not well known, even though it plays a key role in the metabolism of diatoms. There are continuing concerns that toxic dinoflagellate species may be promoted under nutrient imbalance conditions (Berry 1996). Holby and Hall (1994) proposed to maintain suitable ratios of silicon relative to nitrogen and phosphorus by placing cages in areas well supplied with fresh seawater and adding biogenic silica to the formula of the feed used.

The degree of impact from effluent wastes depends on husbandry parameters, including the species, culture method, and feed type, and on the nature of the receiving environment in terms of physics, chemistry and biology. The effect that dissolved wastes may have on the environment will also depend on the speed at which these nutrients are dispersed before being assimilated by the pelagic ecosystem. Cage structures are often located in areas of partially restricted exchange, because such locations generally provide shelter from extreme weather, thus protecting staff and equipment. In restricted exchange environments, it is essential to estimate flushing rates in order to asses the risks of significantly increasing nutrient concentrations in the immediate environment. Recent advances in our knowledge have greatly improved the situation in many areas. Several studies in various countries have calculated the cycling of nutrients; the loss of nutrients can be calculated by simple equations or by mass balance equations (Braaten 1992).

It is possible to minimize environmental impact by combining different tools in an impact assessment – the mass balance equation, the flushing rate, the characteristics of the site (depth, current, etc.) – of the farm. In Norway, a management system termed "modelling on-growing fish farm monitoring (MOM)" has been adopted, which combines simulation modellings of potential environmental impacts with a monitoring programme of increasing elaboration, dependent on the model's predicted scale of impacts. The monitoring has to ensure each farm's compliance with a set of required environmental quality standard (EQSs) (Pearson and Black 2000).

Effects of chemical use

Vitamins (e.g. vitamin B12 and biotin), minerals and pigments are often added to compounded feeds, but such additions are not common in the tropical and sub-tropical areas, where trash fish is mainly used as feed (e.g. for groupers, yellowtails). It is thought that the stimulating effects of vitamins and fish wastes have had an affect on the growth of red tide species, which have been reported in several studies (Wu 1995).

Therapeutants (such as malachite green, formalin, copper sulphate, etc.) and medicaments or antibiotics (e.g. aureomycin, oxytetracycline, terramycin, furazolidone, etc.) used to treat fish diseases are sometimes applied, and have resulted in the development of antibiotic resistant bacteria. The development of resistant bacterial pathogens of fish is well documented. For example, 100% bacterial resistance to oxytetracycline has been recorded from marine sediments near a fish farm after medication, which persisted for more than 13 months (Samuelsen, Solheim and Lunestad 1991).

Anti-foulants, typically copper based, are often used to treat cage netting to control fouling. There is a need for further research into the fate of releasing copper into the marine environment in this way, and its potentially polluting effects on planktonic and benthic flora and fauna (Mackay 1999).

Algal blooms

Toxic algal blooms have affected marine fish farming and will surely continue to do so. Algal blooms are mainly stimulated by the nutrient enrichment of waters (Figure 135), mainly by nitrogen and phosphorus compounds (Figure 136). When these blooms occur, there is a significant impact on the fish being cultured. Toxic species of the genera *Chattonella*, *Heterosigma* and *Gymnodinium* can cause massive fish kills and generate severe economic losses (Daranas *et al.* 2001; Fogg 2002; van den Bergh *et al.* 2002).

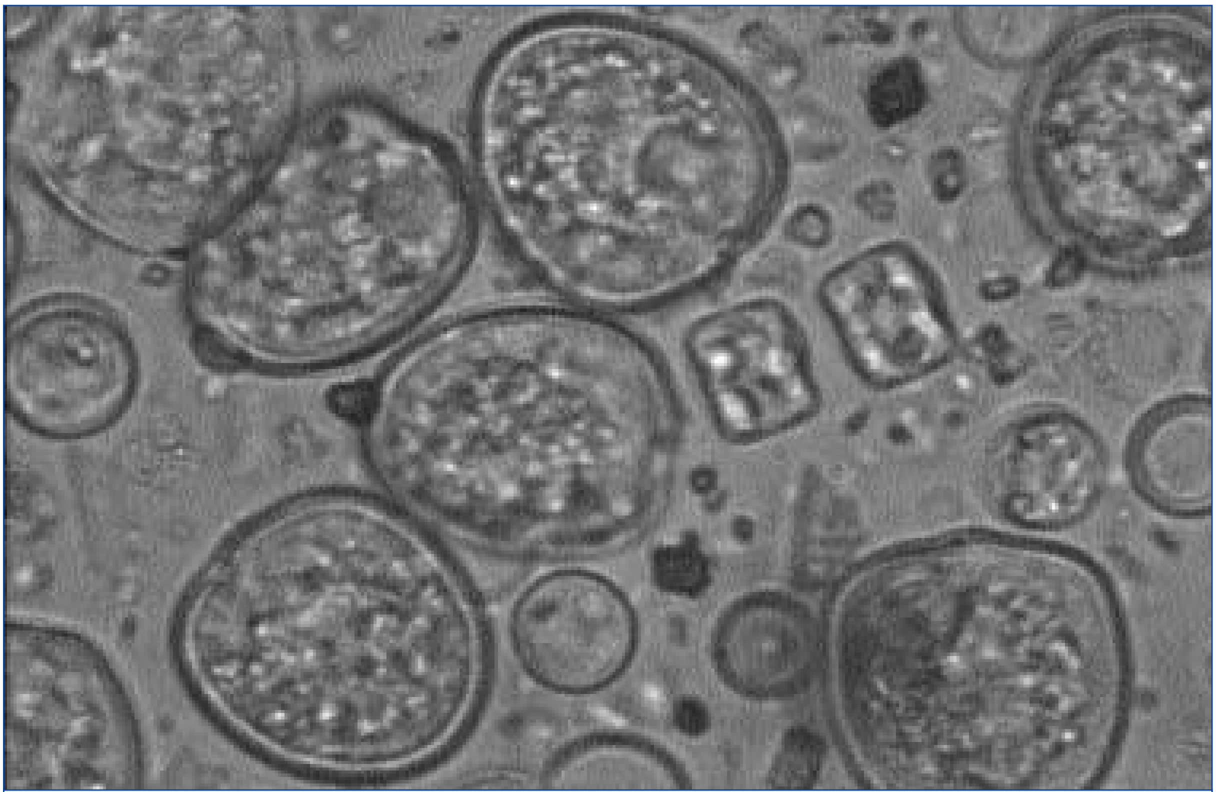


Figure 135. Bloom of dinoflagellates *(Prorocentrum minimum)* in Italian coastal waters, caused by organic pollution (x1 000) (Photo: P. Giordano)

Algal growth can also be accelerated by the presence of extraneous chemicals such as the use of vitamins in artificial feed. Biotin has been shown to stimulate the growth of certain toxic phytoplankton species (*Gymnodinium aureoles*); vitamin B_{12} can promote the alga *Chrysocromulina polylepis* (a "salmon killer") and the dinoflagellate *Heterosigma hakashiwo*; while fish meat and faeces has been shown to stimulate the growth of red tide species such as *Gymnodinium* sp. and *Chattonella antiqua* (a "yellowtail killer") in laboratory conditions (Wu 1995). Since 1957, large-scale red tides have been reported in the Seto Inland Sea of Japan. Since 1964, these phenomena, which are due to harmful marine phytoplankton, have spread throughout the whole area of the Inland Sea. In the summer of 1970, a red tide of *Chattonella antiqua* caused the death of 500 000 yellowtails, valued at ¥ 620 million. The capture-based aquaculture of yellowtails in the Seto Inland Sea has regularly suffered since that time from outbreaks of red tide due to *Chattonella* spp. The effect of *Chattonella* on the gills of the Japanese amberjack *S. quinqueradiata* has been studied: fish dying from *Chattonella* exposure show many types of lesions, while the gills of fish dying from environmental hypoxia show very few lesions. This demonstrated that the branchial oedema was induced by *Chattonella* and not by hypoxemia (Ono *et al.* 1998; Hishida, Ishimatsu and Oda 1999; Fogg 2002).

Along with the promotion of aquaculture, the establishment of monitoring systems for red tides and efforts to remove its causes are urgently needed.

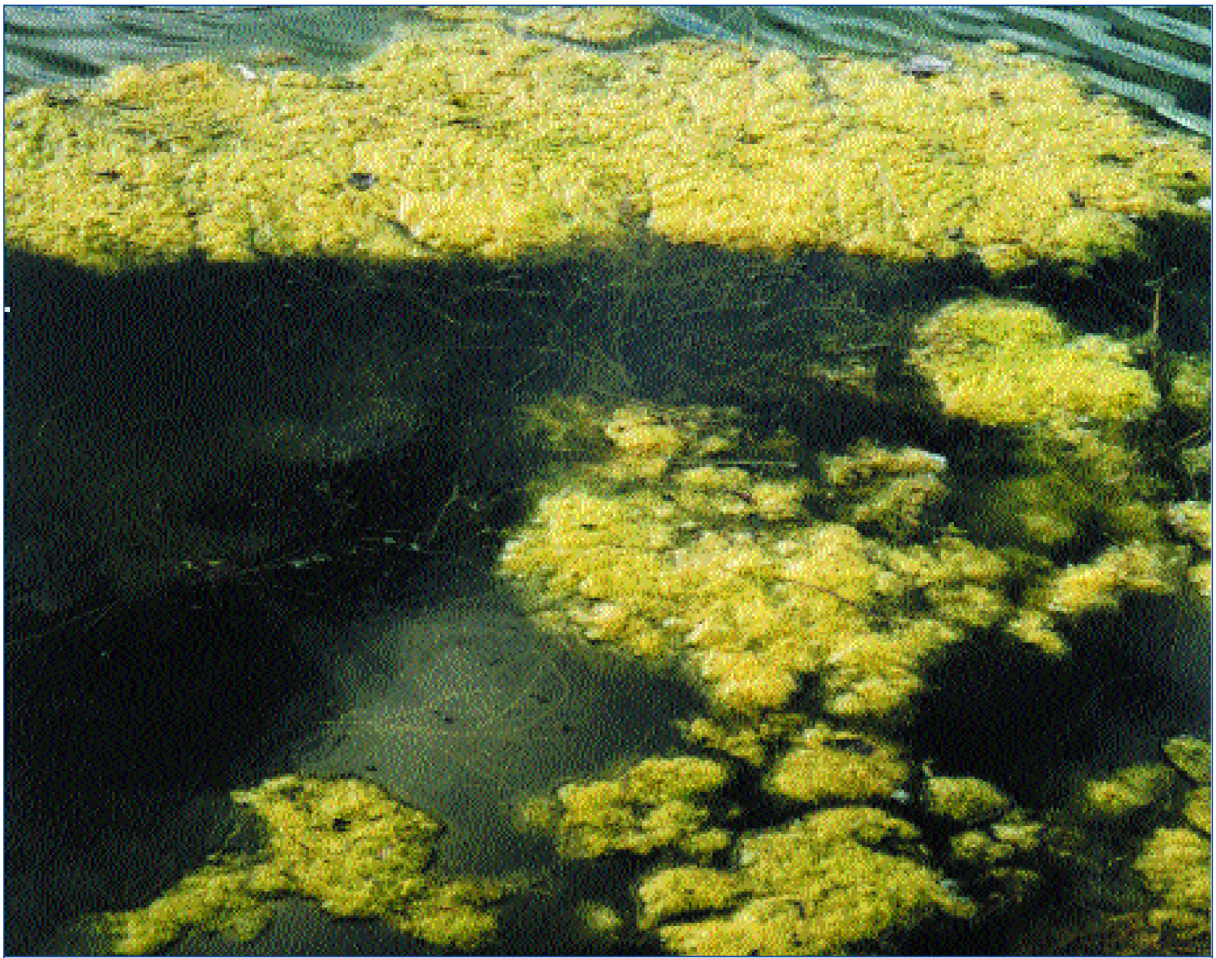


Figure 136. High nutrient concentration causes algal blooms in coastal areas
(Photo: C. Silvestri)

Benthos modification

Changes in macro-benthic community structure have been observed along a farm waste enriched gradient, with a decrease of the number of species. As detrital input increases, diversity also initially increases because there is the opportunity for the expansion of existing populations and the immigration of additional species. However, constant and long-term changes in water quality and physical and chemical conditions in the deeper level of sediments allow opportunistic species to proliferate, and longer lived species to disappear. Eventually, if input levels increase, the surface sediment becomes anoxic and only a small number of specialist *taxa* can survive (Mazzola, Mirto and Danovaro 1999; Mirto *et al.* 2000). A bio-indicator of polluted marine sediments is the polychaete *Capitella* sp., which is present in high abundance in these nutrient rich areas (Chareonpanich, Tsutsumi and Montani 1994).

Enrichment in organic matter, and the reduction of light due to fish farming and cages can cause a decline in sea-grass meadows (in the Mediterranean, the regression of *Posidonia oceanica*). Fish farming represents an additional anthropic disturbance on these already endangered sea-grass communities. Recent studies (Delgado *et al.* 1997, 1999; Pergent *et al.* 1999; Ruiz, Peréz and Romero 2001) show that *P. oceanica* disappears under fish cages, while surrounding areas are significantly degraded. This can be attributed to a direct reduction in light availability by the shading effect of the cages themselves and the high concentration of organic matter in sediments that is caused by the settling of particulate organic matter, such as uneaten food and faeces. Both factors are critical to sea-grass for survival (RuizRuiz, Peréz and Romero 2001). Sea-grass decline can also continue after fish cage activity ceases; Delgado *et al.* (1999) reported a case in which the aquaculture activity ceased in 1991, yet the *P. oceanica* meadow declined until after 1994.

Studies to evaluate differences in the seabed community structure have been undertaken by Murcia University in the region of Murcia, Spain under tuna farming cages. These showed that the diversity of seafloor life beneath the cages is significantly lower than other areas, due to the inputs of organic matter from the feeding of the tuna (Marín *et al.* 2002).

Other interactions

Losses caused by predators to the fish farming industry itself are well documented. Whether by birds, seals, sea lions, carnivorous fish or even man (poaching), the potential commercial implications can be severe, not only in terms of fish loss, but in terms of the cost of the anti-predatory methods necessary (nets, security personnel, etc.). Nash *et al.* (2000) considered such losses as a severe threat to aquaculture businesses. In Tasmania, Australia, 235 attacks by male fur seals on 15 farms producing Atlantic salmon and rainbow trout were recorded in 4 months, and one farm lost more than A$ 500 000 of fish in a single year. More recently, the loss by the industry to pinnipeds has been estimated by the Tasmanian Salmonid Growers Association at 2% over a 6-month period.

In the capture-based aquaculture of southern bluefin tuna a problem with mammal interactions exists as well. Marine mammals bite through the mesh and create holes in the nets of the cages, attacking the fish. The market-related risk is twofold: the potential loss of fish through the hole, and the reduction of the final quality of the harvested fish. Fish that have survived an attack (tuna could easily die from the stress) are badly scarred, loosing their full market value. In Port Lincoln, Australia, during the harvesting period, abalone divers have to cease all activities, since they face a high probability of meeting white pointer sharks, attracted by tuna blood and, probably, tuna stress movements in the cages. A few years ago, a white pointer shark was found inside a tuna cage. Apart from the production-related risk, it is necessary to consider the safety of the staff working on these aquaculture sites. Male sea lions have also been known to attack divers working on the nets. Sea lions generally bite or pull at the flippers of divers, but body bites have also been reported, particularly once the predator is inside the cage net (Nash *et al.* 2000).

Conclusions

The interaction of capture-based aquaculture with capture fisheries and traditional forms of aquaculture lead to potential environmental impacts, which are not always clearly defined or fully understood.

The impact on wild fish stocks as a result of catching wild “seed” is an important issue, but it is not easy to know the real status of stock resources. Knowledge of the effects of fishing on fish community dynamics is generally incomplete. Reasons for the decline of a resource cannot be evaluated without specific research, but even with scientific data it is often difficult to evaluate its status, because of other interacting effects (such as natural environmental events) that affect recruitment.

Where capture-based species are of significant commercial importance, it is more difficult to evaluate exactly the resource availability because other fishermen exploit the same stock, sometimes locally or, in the case of tuna (a highly migratory species), on a quite global scale. In many areas, high levels of fishing effort have caused increased recruitment overfishing of the life cycle of different species that are used in capture-based aquaculture, thus increasing their vulnerability to commercial extinction. Even "low level" artisanal fisheries can adversely affect stocks; a large proportion of the world's species (e.g. grouper) are caught by traditional methods (Morris *et al.* 2000).

It is clear that there is a strong need for more and better data on the biology and fisheries of the target species used in capture-based aquaculture. This is essential if the sector is to survive alongside traditional fisheries and to serve as a basis complete enough to predict the sustainability of the industry. The main objective must be to achieve a degree of knowledge that could make the evaluation of the maximum sustainable yields (MSY) possible.

The capture of wild "seed" for this form of aquaculture is not the only issue to be considered as having potential negative interactions with the environment; habitat destruction, pollution, bycatch, feeding impact, etc., are all areas that also need more research to ensure the sustainability of the sector. The combination of these effects is difficult to understand owing to the lack of specific studies; this is particularly true for the new capture-based aquaculture species.

The importance of good feeding management should be highlighted. A common problem, found in the operation of all capture-based aquaculture activities, is the lack of specific diets that adequately match the nutritional requirements of each species. The palatability of such feeds is also of major importance. The extensive use of trash fish produces several environmental impacts and is one of the major sources of pollution around culture areas. The work now being undertaken to create and adopt formulated artificial diets could mitigate this problem. It is in the long-term interests of producers that successful specific research leading to the formulation and manufacture of commercial artificial feeds should be conducted, in order to maintain profitability and limit environmental degradation.

Finally, the effects of capture-based aquaculture on the environment can be significantly reduced by careful site selection, supported by good pre-site selection and pre-development appraisal of those farm locations that are envisaged, using modelling and other available assessment methods. Control of stocking densities, good feeding regimes, good health management and accurate environmental impact assessments (followed by continuous monitoring) should always be carried out.

chapter 8

SOCIAL AND ECONOMIC IMPACTS

8

SOCIAL AND ECONOMIC IMPACTS

Introduction

Markets have been the driving force behind the development of the capture-based aquaculture industry. Market requirements are determined primarily by consumers' tastes and customs, as is the case for bluefin tuna capture-based aquaculture. The preparation of the traditional Japanese "*sashimi*" fostered the high demand for this high quality species, hence the development of its capture-based aquaculture.

All businesses must keep good records to be profitable and successful: capture-based aquaculture is no exception. Good record keeping is essential to understand the successes, failures and profitability of any venture. High profitability, coupled with high market demand, have ensured the development of this activity. However, the increase in capture-based aquaculture is bringing about a number of very important and diverse socio-economic effects, not all of them beneficial.

The selection of species to be cultured is driven by their acceptability in local, national or international markets. Capture-based aquaculture systems can be completely different, depending on cultural, economic, ethnical opinions and local traditions. Cultural and ethnical heterogeneity, as well as economic differences, are partly reflected in the organization of the fishing and farming activities, and in the technologies used.

In Asia, capture-based aquaculture activities may be constrained by the lack of appropriate technologies and limited investment. For example, the capture-based aquaculture of groupers is typically small scale and artisanal, while that for tuna is high-tech and requires considerable investment. The latter type of culture is normally invested in by international companies in partnership with local operators.

Socio-economic considerations differ, according to the species and the country. The capital requirements of grouper farms are low and family or community orientated, yet the income can have a significant influence on the local/rural economy. There may be several incomes generated in the local economy, from the "seed" catchers to the feed suppliers and the merchants. Tuna farming, when operated by international companies, has significantly lower impacts on the local economy, since the "seed" fish are taken on the high-seas and the products are sold on international markets. The income from tuna operations tends to be localized as wages, while the real profits are made by international companies.

The exploitation of a common resource does not always benefit society at large. It can create conflicts between fishermen, farmers and other resources users (e.g. tourism and shipping), and the risk of the concentration of the benefits into a few hands is often compounded by a lack of appropriate regulatory framework. Impacts, be they positive or negative, are not always predictable because capture-based aquaculture is a novel activity with little past history, and the characteristics are species-specific. It is thus very difficult to have a perspective of the entire socio-economic spectrum. Conflicts with other competing resource users, and with other sectors, are unpredictable in the short term, and there is a need for specialized sector research (marketing, environmental, socio-economic, etc.).

Economic issues

Capture-based aquaculture products are seen by many to fill distinctive niches in the seafood market, being of high value and high quality. These products will complement, but sometimes also compete with, those supplied from the wild fisheries or other aquaculture systems. In the short- to medium-term, the main factor that will determine the development of capture-based aquaculture is the ability to build up and maintain high value markets (Figure 137). However, environmental restrictions (sites, "seed" availability), environmental degradation from waste products, diseases, and competition for limited resources may all constrain such developments in the case of some species.

Capture-based aquaculture can contribute significant positive social and economic functions at a regional level, particularly in those regions with depressed and marginal economies that are characterized by high rates of unemployment and emigration, and with a generally low standard of living. The economic benefit depends on the country and the species being farmed, as indicated below.

Figure 137. Tuna being sold in the Tsukiji (Tokyo) fish market (Photo: P. Miyake)

The economic value of tuna capture-based aquaculture in the Murcia region of Spain now represents eight times that of all regional fisheries. This evolution is due to a very rapid response to Japanese market demands, and the development of strong partnerships with Japanese companies (de Monbrison and Guillaumie 2003). New markets in the USA and Europe had been developed in 2001; exports to Europe were said to be up by 50%, to America by 76% and to Asia by 3%. Bluefin tuna farming in Croatia is managed by 6 commercial companies using 9 lease sites. The economic benefit from capture-based aquaculture to the fishery sector is worth approximately € 50 million.

In Australia the tuna industry started in 1990 and has now developed into its largest farmed seafood sector, with a harvest in 2000/2001 of 9 005 tonnes, worth A$ 263.79 million (Clarke 2002). However, its long-term sustainability in Australia is largely dependent on a reduction of its reliance on imported frozen bait fish for tuna feed. At present, 45 000 tonnes of bait fish are used annually, of which about two thirds are being imported, primarily from the USA and northern Europe. Continuous quality improvement is compromized by the need to use a wide variety of bait fish of different composition and quality. Other problems include quarantine restrictions on the use of some feeds to certain times of the year, and fluctuations in the availability and price of bait fish (www.sardi.sa.gov.au). As a result, the feeds used constitute one of the highest operating cost factors.

Since 1998, the rising demand for bait fish (sardine, mackerels, squids, etc.) in the Italian market has caused sharp price increases for frozen mackerels for bait (75%), frozen squids (40 to 110%, depending on the size and the quality) and sardines (80%) (Miyake *et al.* 2003). In Spain, gilt sardine accounted for less than 5% of the landings in 1993; by 1999 the percentage had risen to almost 35%, mainly because of capture-based aquaculture, and gilt sardine prices doubled in 5 years (de Monbrison and Guillaumie 2003). Production and investment costs are also rising; the cost of boats for fishermen and equipment for farmers can also affect profitability, but these must be evaluated against the increases in prices for the products produced. However, the Japanese market for premium tuna products has been slowing down since 2001, and this will have an impact on new investments (de Monbrison and Guillaumie 2003).

The expense of feeding is also the main problem in yellowtail capture-based aquaculture. Since the 1980s, Japanese yellowtail farmers have had a difficult time as production costs have increased with the rising costs of feed, due to the drastic decline in the volume of sardines caught in Japanese waters, a poor supply of Japanese amberjack juveniles ("*mojako*"), and the stagnant Japanese economy. At the same time, the more valuable greater amberjack (*Seriola dumerili*), and yellowtail amberjack (*Seriola lalandi*) were becoming more attractive to fish farmers, and the number of "*mojako*" stocked for aquaculture started to decline in 1995. Yellowtail culture is today facing difficulties and farmers are trying to introduce new species to make capture-based aquaculture more profitable. Greater amberjack aquaculture has been growing rapidly, and this species has now become a rival to Japanese amberjack. Because of its high flesh quality, the greater amberjack usually commands a much higher price than cultured Japanese amberjack in wholesale markets, and the yellowtail amberjack is highly sought after as a "*sashimi*" ingredient (Nakada 2000). This has established the yellowtail amberjack as a valuable new cultured species in South Australia and other locations.

Japanese amberjack fry are cultured in Japan from the size of 4-5 g, and their price in 1998 was ¥ 15 000/kg. Farmers had been able to maintain annual production at 140 000-160 000 tonnes until 2000 but the number of farms had decreased from its peak of 3 991 in 1977 to 1 815 in 1996 (Nakada 2000). Recently, the domestic supply of "*mojako*" showed a significant decrease, and a few million juveniles were once again imported from the Republic of Korea. The price of greater amberjack juveniles ranges from ¥ 2 500/kg to ¥ 10 000/kg. Via Hong Kong, Japan has imported wild juveniles caught in China and Viet Nam since 1986. However, the importation of wild fry, fingerlings, or juvenile fish has been a source of disease; the Japanese aquaculture industry spent ¥ 13.9 billion for the medication used in fish culture during 1997. In 1998, the average production cost for a Japanese amberjack adult was ¥ 750/kg, while its market price was ¥ 1 050/kg.

A cost analysis for the years 1992-1997 is shown in Figure 138; according to Nakada (2000) the gross profit was not as good as in previous years. The cost of juveniles increased as a proportion of total expenditure; feed costs also increased because of a drastic decline in the sardine resources around Japan. Though not shown in Figure 138, total production changed little during the period, even though the number of the fish farmers declined.

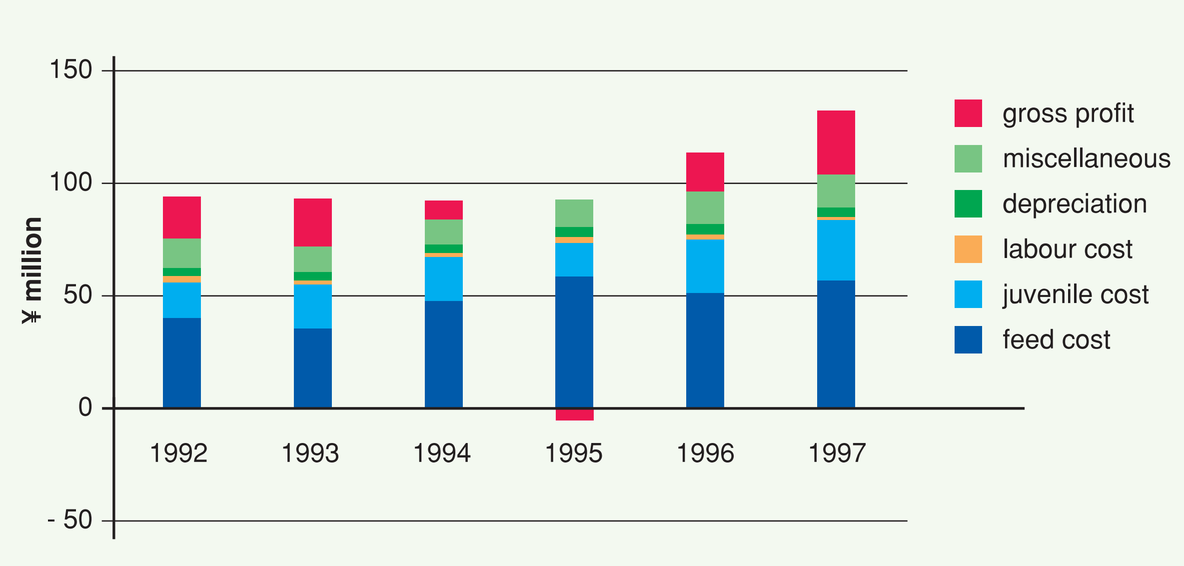


Figure 138. Costs and returns of Japanese amberjack culture (Nakada 2000, modified)

High-density culture is becoming common practice, in order to compensate for falling profits, but it can lead to pollution in the culture areas. It has been established that fish eat less in overcrowded conditions, resulting in poor growth and with an increased susceptibility to diseases. Fish farmers are now trying to use formulated feeds instead of raw fish; when these expensive diets are used, effective feed utilization is essential, but they are more environmental-friendly. In order to overcome their problems, fish farmers are becoming aware of the importance of maintaining good records on stocking density, and carefully compute the daily feed used, based on feeding tables that reflect fish size and water temperature. New technologies, including underwater cameras and counting systems, are used to assess stock numbers and therefore stocking density. Computer programs are extensively used to generate feeding tables and create stock recording systems. The use of formulated feeds (Figure 139) with balanced nutrients has made production of high-quality fish with firm flesh and no fishy odour possible. This practice has also created a new demand for cultured products, for use in "*sashimi*" and other dishes.

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 Co-operatives, 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).

Mediterranean production of greater amberjack, mainly in Spain, stopped in 1999. In 1992, young fish were captured and sold directly to farms for about 225 pesetas each and their market value

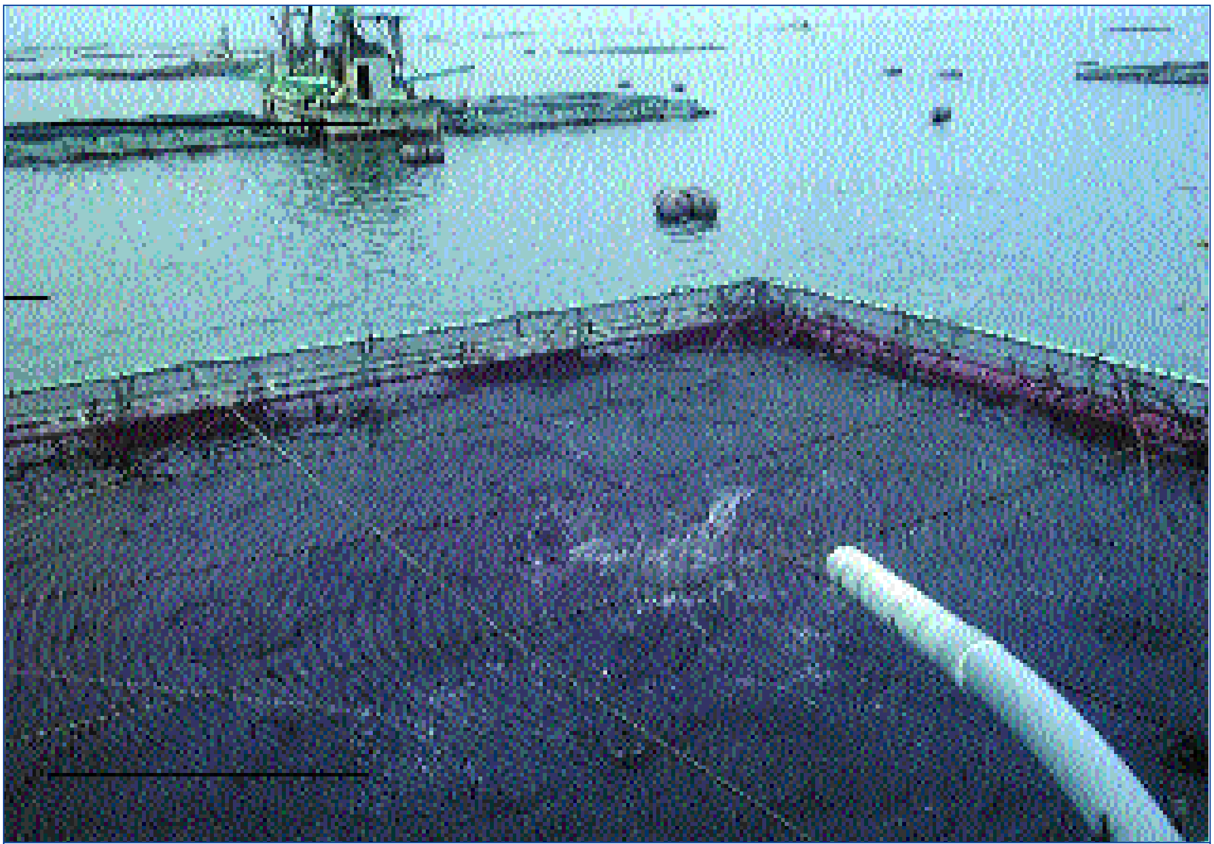


Figure 139. Feeding a formulated diet to Japanese amberjacks in Japan (Photo: M. Nakada)

was about 1 300 pesetas/kg. Compared with yellowtail production in Japan the profit margin was low, mainly owing to the extensive natural fishery for greater amberjack in the Mediterranean and limited demand (Nash 1995). At present in Spain there are no cage farms producing *Seriola*. Some farms devoted to seabass/seabream or tuna are producing it as a sideline, but these are projects to assess the viability of commercial production. The main limitation for commercial operations is the source of juveniles for on-growing purposes: these always have to come from local wild populations, and are either too scarce or too expensive (€ 2-3 for each 50g young *Seriola*) to be interesting as a source for capture-based aquaculture (A. García Gómez, pers. comm. 2002).

South Australia is beginning to harvest yellowtail amberjack (*S. lalandi*) to satisfy increasing export demands. Australian "*hiramasa*" are used for high quality "*sashimi*" in Japan and the USA, and as a table fish in Europe and Asia. "*Hiramasa*" is the second most popular "*sashimi*" product in Japan after tuna. In 2001, 18 tonnes of yellowtail amberjack, destined for the United States, were harvested. With 23 companies from all over the world showing interest, yellowtail farming could turn into a major new industry for South Australia (Anonymous 2001).

In many Asian regions, the focus is 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). Owing to the regional nature of the market, prices can fluctuate wildly, and there is a great need to develop new markets to attain stability to support the sector. According to the NGO TRAFFIC, exports of groupers and wrasses from South East Asia rose from 400 tonnes in 1989 to 5 000 tonnes in 1995. However, exports declined by 22% in the following year. The decline in wild populations of groupers and wrasses was identified as one of the main factors behind the decrease in exports. TRAFFIC estimated that the main threats to reef fish and their ecosystems in South East Asia come from increasing fishing pressures, aimed at ensuring a constant supply for the live reef fish market, and unsustainable fishing methods, such as the use of cyanide.

Hong Kong is believed to be the largest importer of live reef fish for food in Asia and an important re-exporter to other countries. In 2000, imports of high value live marine fish such as red grouper and Napoleon wrasse (*Cheilinus undulatus*) totalled 5 851 tonnes, corresponding to over HK$ 552 million, i.e. some US$ 71 million (GLOBEFISH data). The main suppliers of groupers to Hong Kong are Indonesia, the Philippines, Malaysia and Thailand. In the Hong Kong market, consumers prefer smaller specimens to be served whole rather than filleted; therefore the price of smaller specimens is higher than that of larger fish.

Millions of dollars are being spent on grouper research, with the aim of introducing appropriate practices and reducing production costs for capture-based aquaculture, to make it sustainable. These need to take the fragility of the market into account, should production take off. Investment is also needed on the marketing side to make the industry economically viable (Svennevig 2002).

An example of production costs, revenue and profit of grouper capture-based aquaculture from Thailand is as follows (Boonchuwong and Lawapong 2002): the average annual total production costs per farm were 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% rate of return (net profit/total cost). Feed accounted for 57% of culturing costs, whereas "seed" accounted for 24%. Other costs (opportunity, depreciation, repairs, etc.) accounted for 19%.

The most important individually recorded *Epinephelus* species mentioned in FAO data on aquaculture production (FAO 2002a) is the greasy grouper (*E. tauvina*), which is farmed in Malaysia and Hong Kong; production was worth about US$ 12.4 million in 2000. The second most valuable individually recorded farmed grouper species recorded was the slender grouper (*Anyperodon leucogrammicus*), farmed mainly in Thailand, which was valued at over US$ 10 million in 2000. The value of the areolate grouper (*Epinephelus areolatus*) reared in Hong Kong was much less (US$ 1.7 million). The recorded value of farmed orange-spotted groupers (*E. coioides*) was less than US$ 40 000 in 2000. However, all these figures are put into the shade by the non-specified category "groupers nei", worth over US$ 40 million. This category of farmed groupers was reared mostly in Taiwan Province of China and Indonesia.

Capture-based aquaculture in Indonesia is a value adding process, with potential economic benefits to coastal communities. For example, the economic returns to a Moslem community in NE Sumatra (since 1990) have meant that its members can now make pilgrimages to Mecca, thanks to the profits of the grouper businesses. Individual fishermen earn a significant percentage of their annual income from grouper resources (Sadovy 2000). In Viet Nam, the income from grouper fry/fingerling fisheries contributes 10 to 50% to the annual income of fishermen, and a single fisherman's income from this source can reach as much as US$ 3 080 annually (Sadovy 2000).

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% for exporters and 49.2% 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.

In Italy, European eel culture is carried out on 74 farms which produced 3 100 tonnes in 2000. Their operation depends heavily on "seed" availability; annually there is a requirement for 500 tonnes of elvers or glass eels. "Seed" is collected from the wild and imported (predominately from France) at an increasingly higher cost (1 kg of glass eels, containing 3 000-4 000 glass eels, is equivalent to € 15-41). "Seed" can account for up to 50% of eel production costs (www.regione.emilia-romagna.it/laguna/articolo.asp?id_articolo=510). Since the fall in the availability of glass eels there has been an increase in the average unit cost of eel product, since elvers are often cultured instead of glass eels. The main production costs in eel culture are the costs of elvers (37%), feed (24%) and labour (12%) (Corbari, Mezzani and Rossi 1997). Italian farms produce two market sizes of eel: 130-180 g for Italy and the Netherlands and 300-1 000 g for German consumers. Eel market prices have generally fallen since 1995 (although 1999 saw a 3.2% rise), due to increasing production from North European recirculation systems. Eel production has spread all over Europe, owing to its potential profitability, but consumption remains mainly in the Netherlands and Germany. The market demand for smoked eel in the Netherlands is satisfied mainly from Danish and Dutch farmers, who sell their production directly to processing systems. Other countries, particularly Greece and Spain, have increased eel production for export to North European markets; they have no local market but good culture conditions. In 1998, a Danish laboratory began producing "*kabayaki*" (ready-to-eat eels for Japan), creating a new market for European producers who had been suffering a price decrease in 1996 and 1997. However, the Japanese market has seen prices decline, due to domestic crises and increased production from Chinese farms. Good eel quality is an essential part of a marketing strategy, and producers are increasingly aware that diets and post-harvesting processes contribute to improving the overall performance of the sector (www.aquaguide.com/databank/tesi/capitolo_5.html).

Social impacts – employment creation and skill development

Social benefits are often closely related to economic benefits. The development of a new industry has the potential to create jobs. In the case of capture-based aquaculture, these employment opportunities often arise in rural coastal communities where jobs are limited. There is also a relationship with the fishing industry. With the constant reduction in fishing opportunities, another fishery-related industry is a welcome alternative for the existing skilled workforce. The drift of young persons to cities can also be reduced if job opportunities become available in a new dynamic sector that has the potential to generate high incomes.

Bluefin tuna farming has brought some changes to the Mediterranean tuna fishing industry. Tuna fish prices rose for fishermen and completely changed operational procedures (including fishing areas and seasons, as well as fishing operations). There has also been an increasing demand for purse seines, which are used for the collection of live bluefin tuna (Miyake *et al.* 2003). The fishing sector in Croatia has been significantly influenced by the development of bluefin tuna capture-based aquaculture. After Australian emigrants successfully transplanted Southern bluefin tuna fattening techniques the practice developed very quickly. In just one year, purse seine fishing vessels increased from 19 (1999) to 30, in order to guarantee the supply to tuna farms. The same phenomenon has happened in France, mainly as a consequence of the increasing number of capture-based tuna farms in Spain; from 1995 to 2000 the number of vessels forming the specialized blue-fin tuna fleet increased from 21 to 32 boats (de Monbrison and Guillaumie 2003). The increasing number of purse seine boats (also in other Mediterranean countries) contributes to the modernization of the fleet, better shoal detection efficiency, speed, improved safety, catch handling systems, and crew comfort.

Many fishermen have become active partners in farming activities, either as suppliers or tuna farmers. Some fishing vessels are employed in capturing the small pelagic fish used as feed for caged tuna. In Croatia, trawlers have been fully integrated into tuna farming operations, either for transporting live fish or delivering feed to the farms. Tuna farms offered a very important employment source in the heavily depopulated Croatian islands; 300 farm jobs have been created (Katavic, Vicina and Franicevic 2003b). In the Murcia region of Spain the bluefin tuna industry provides 500 direct jobs. The employees are young – 25-35 years old and the majority are working as divers at sea (de Monbrison and Guillaumie 2003).

The catching cost in Australia (i.e. use/waste of resources) of bluefin tuna for capture-based aquaculture (purse seine system) is lower than high seas long-lining, namely A$ 3.50/kg versus A$ 22/kg (B. Jeffriess, pers. comm. 2002). Australian capture-based tuna aquaculture has had a significant economic multiplier effect because of its labour intensiveness (350 direct and 700 indirect jobs) associated with operations, infrastructure requirements and the exporting of fresh chilled and frozen product. In the area where farming takes place, bluefin tuna farming has brought social stability to the tuna industry, as wild tuna fishing forces crews to remain absent from home for very long periods (B. Jeffriess, pers. comm. 2002). Working conditions are better than on the fishing boats (regular hours, regular salaries, weekends on shore).

The development of new skills has been important for harvesting operations, for example in Australia, where a specialized team of divers crowd the tuna into a small area inside the cage using a sweep net, and then capture the bluefin tuna directly by hand (Figure 140); tuna reach an average weight of 50 kg. This technique is very important and it is essential to have experienced divers who do not stress the tuna too much, as this influences product quality.

Figure 140. Divers are indispensable in bluefin tuna capture-based aquaculture activities (Photo: L. Mittiga)

Specialized divers are professionals dedicated to tuna capture-based aquaculture. They are fundamental to many farm activities, including inspections of the cages for mortalities, mooring and net integrity, and for transfer after collection and killing procedures.

Figure 141. Specialist employees in a capture-based aquaculture system for Japanese amberjack (Photo: M. Nakada)

Value-added benefits

New opportunities arise from the production of capture-based aquaculture operations. However, to take advantage of them, marketing strategies need to consider the availability of the basic resource, in this case the capture-based aquaculture species itself. The possibility of tapping the potential for livelihood improvement through this activity depends on the adoption of appropriate technologies or their transfer or modification for local application, having been tested to determine their economic viability. Lack of technology and high costs are typically considered as the main obstacles for resource exploitation. Appropriate technology needs to be adapted to suit the needs and limitations of each region. A balance has to be found between maximum sustainable production and environmental sustainability that first of all safeguards the livelihoods of the local communities, while providing products that can access existing and develop new markets.

Capture-based aquaculture activities in Asia often employ inappropriate technologies and skills; fish farmers may therefore be forced into using unsustainable practices. The use of wild fry puts stress on fish recruitment for the capture fisheries and on the biodiversity of the capture areas. There is also a lack of fry availability for most of the species used in capture-based aquaculture.

The present use of trash fish as feed leads to various constraints on production, as well as having a negative environmental impact. The currently available "traditional" cage technology also forces the farms to cluster in very sheltered areas (Figure 142).

Figure 142. Artisanal capture-based aquaculture system in Southeast Asia (Photo: S. Fazi. Coastal Resource Management and Sustainable Tourism in Ulugan Bay project implemented by UNESCO/CSI and the Puerto Princesa City Government with the support of UNDP)

The results of these practices are fairly predictable and eventually lead to serious negative environmental impacts, which cause production constraints and diseases or low growth performance, due to non-suitable water quality (high levels of suspended material). The lack of, or expense of new or improved technology deters newcomers from entering the business and restricts the families of landless fishermen from exploiting this livelihood opportunity. Farmers have had to focus on shortcuts in collecting and keeping wild fry, competing with capture fisheries for stocking material. Often, they only benefit from capture-based aquaculture by applying better logistics to the marketing of live and very high-value fish, such as groupers. Frequently, very limited value is added to the product through real growth of the fish biomass, with only 25-30% being added to the sales price (Svennevig 2002).

Focus in Asia has been given to the lucrative live fish market. This is a logical strategy for the farmer, and is the most immediately accessible market segment. Sale prices in this specialized market more than cover the production costs and provide a reasonable return to the farmers. However, this market is not controlled by the farmers, but by the wholesalers, who have the highest profit margin and little interest in the well-being of their supporting farmers (Svennevig 2002).

Another issue within the grouper "live fish" segment is that the Hong Kong market; though being the target of grouper production for most of the countries in the region; it trades a limited volume – 5 000 tonnes/year. It is therefore predicted that the market will show a "normal" supply/demand collapse when the large RandD effort put into grouper culture becomes fruitful and production increases. This will leave some farmers in a very vulnerable situation, especially those that still only use the present technology and methods of farm management. If they do not diversify the market segment for their products there will always be risks of the market collapsing from increased production.

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 blue-fin 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 € 3-6/kg in Japan versus bluefin tuna sold at € 20-40/kg.

Impacts and conflicts with other resource users

Capture-based farm installations can be a source of conflict in coastal zones. Conflicts may be direct or indirect; affecting activities such as navigation, tourism and other fishing operations. Conservation of valuable natural resources are dependent on the presence/absence of national/regional legislation. Farms in Italy are not allowed to be located close to *Posidonia* sea beds, but other countries do not always take up their political responsibility to protect and manage these fragile and endangered ecosystems.

Capture-based tuna aquaculture activities in the Mediterranean area have caused friction between the local tuna fishermen that use long-lines and the cage towing operations of capture-based farmers. Since the activity of tug boats towing tuna cages was disturbing the traditional long-line fisheries of Italian, Maltese, Tunisian and Japanese fleets, as well as reducing tuna catches, the Maltese national delegation to the GFCM 26th Session in September 2001 proposed the establishment of a box in the international waters south of Malta that would be closed to purse seine fishing (Tudela 2002c). The artisanal fisheries could not compete for the resource against advanced industrial fleets with large catching capacities, which exploit acoustic and aerial surveillance methods (Tudela 2002a,b).

Bluefin tuna farmers in Croatia have caused problems due to the smell and pollution during the summer season. The uncollected fat skim on the sea surface, which comes from the feeding of oily trash fish, may spread outside licensed zones, and can have disastrous effects on the beaches used by tourists (Katavic, Vicina and Franicevic 2003b). In France, the biggest fresh tuna market in Europe, five companies specialized in bluefin tuna have had negative impacts on local employment opportunities with a 20% reduction in people employed in the sector. This is due to the tunas being moved to the Spanish farms in Murcia for on-growing instead of being sold to supermarket chains in France (de Monbrison and Guillaumie 2003). In some cases, however, tourism has been used to increase farm profits. There are guided tours to the offshore tuna cages in Port Lincoln (Australia); in Murcia (Spain) sport diving in bluefin tuna cages was allowed until recently, when a diver was accidentally hit by the fin of a tuna (de Monbrison and Guillaumie 2003).

In the developing countries of Asia, capture-based aquaculture could have a positive impact. Hair *et al.* (2002) considered the advantages of using capture-based juveniles to supply the ornamental and live food markets for fish from coral reefs. There has been an increasing interest in using this practice. In this case, capture-based aquaculture has had to overcome problems resulting from overfishing of adults and the use of destructive fishing techniques, in particular sodium cyanide solution. Two sampling techniques, light traps and cast nets, have proved suitable for the capture of live pre-settlement fish, and substantial progress has now been made in applying these methods to the development of artisanal fisheries for ornamental species. Although the capture and culture of postlarvae 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 increases the value of the fish caught and reared in an environmentally sustainable manner (Wood 2001), and provides sustainable economic returns from coral reef resources for coastal villagers. The live reef food fish trade, conducted mainly through Hong Kong (30 000-35 000 tonnes/year) had a total wholesale value of US$ 490 million at the end of 1999 (Chan 2000a). Some difficulties have been experienced as capture-based aquaculture activities have increased (wild-caught groupers may be 30% more expensive than farmed fish), and the supply to the ornamental industry (in particular groupers) has been insufficient to meet consumer demand.

The islands of Bermuda provide an example of conflicts between cultural traditions and the environment. 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. This case appears to be a conflict between ecological concerns (the depletion of the fish resources) and cultural ones (the rights of generations of fishermen and farmers who depend on the fish for survival). When reviewing the economic impact of the ban, it becomes clear that the major reason for it was that the tourism industry was – and still is - significantly more profitable than the fishing industry. Various reef related activities (excluding fishing) yielded approximately US$ 9 million in 1988, whereas the fishing industry generated only US$ 2 million in this same period. Thus, “from a strictly cash viewpoint, reef preservation appears to be more than four times more valuable than the pot fishery” (www.american.edu/ted/bermuda.htm).

Conclusions

For some countries, capture-based aquaculture represents an alternative livelihood for local coastal communities and can have significant, positive economic returns in those regions with depressed and marginal economies. The main limitation to the potential for the development of capture-based aquaculture is the small market volume and the exclusive niches that its products seek to exploit, e.g. live groupers in Hong Kong. Fresh fish (the main product for capture-based farmed species) fetches significantly higher prices than frozen and the incentives to enter this market are significant (Valdimarsson and James 2001).

The marketing of fresh fish and, in particular, "live fish" is difficult, due to the perishable nature of the product and its very short shelf life. This increases the economic risk for the producer, and the costs of product transportation to the market, e.g. the air-freighting of tuna from Australia or the Mediterranean to Japan. Large volumes of fish need to be marketed close to where they are landed and these markets often do not pay the best prices. However it is in the best interests of producers to investigate and develop markets for new products in the sector.

Economic analysis shows that the key input is feeding (feed comprises up to 70% of operational costs), which is typical for most intensive aquaculture operations. The lack of specific diets for capture-based aquaculture means that production is dependent on the availability of bait fish and, as has been seen in recent years, prices for these fish are rising. Yellowtail farmers have already had a difficult time due to a significant decline in the volume of sardines caught in the waters around Japan. The long-term sustainability of southern blue-fin tuna capture-based aquaculture will, in a large measure, be dependent on a reduction in the reliance of the industry on imported frozen bait fish and the development of efficient manufactured diets. Benefits of capture-based aquaculture have been demonstrated by the tuna farms in the Murcia region of Spain. Their production now represents eight times the value of all other regional fisheries. This evolution is due to a very rapid adaptation to the Japanese market demand, and the development of strong partnerships with Japanese companies.

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% 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 the future profitability.

In Asia, there has been 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.

In the future, the capture-based aquaculture of target species such as yellowtail may expand, for example in Australia, leading to increased competition. Increasing production may lead to a fall in market prices, unless the producers develop new market strategies and new markets. However, to enter new markets, the products from capture-based aquaculture must look for unique selling positions (USP) to identify their products, and to maintain the exclusivity which exists at the moment. All future developments and increases in production must be market led. The future will also depend on the ability of operators to reduce production costs (e.g. with improvements in growth rate, food conversion, disease control, etc.). There are also specific skills gaps that are evident in the sector, including specific knowledge on economics and management, the suitability of individual species for culture, information on the biology and dietary requirements of the species, and the marketing of the selected species and products.

One of the most important factors for the effective development of capture-based aquaculture enterprises is a rational selection of experts to assist in the design and initial operation of each project. All projects must be established in a logical and economically structured manner, with the associated technical, engineering, biological, environmental, marketing, and financial analyses. Only if all of these criteria are met should a project be considered for investment. An aid to proper project development would be the collection of data on existing farm operations where many of the key elements can be identified and costed – SWOT analysis would reveal where the investment is at risk of failure, and improvements can then be added to new or existing projects. The capture-based aquaculture industry needs the right mix of skills and knowledge to achieve its potential. There will be a need for partnerships between the business sector and those involved in education, research and government.

Capture-based aquaculture can have significant economic multiplier effects, due to the labour intensiveness associated with operating and infrastructure requirements, the exporting of fresh, chilled and frozen products, etc. Related activities can generate a significant number of jobs and a very significant income; in some cases capture-based aquaculture has brought social stability (e.g. in Port Lincoln, Australia) with better working conditions. It can also contribute to poverty reduction in developing countries, and enhance the overall welfare of low-income, resource-poor or asset-poor households.

Capture-based aquaculture, like every business, can and will have negative and positive impacts on the local economic and social climate. Positive or negative interactions due to capture-based aquaculture will be more or less marked according to its level of development and the technology used and species cultured. The challenge will always be to try to create a balance that provides a positive answer to the overall equation.

chapter 9

MANAGEMENT OF RESOURCES AND CULTURE PRACTICES

9 MANAGEMENT OF RESOURCES AND CULTURE PRACTICES

Introduction

The exponential growth of the global population and the associated need to produce enough food impose considerable pressure on the supply of natural food sources, including marine resources. Since the creation of the International Council for the Exploration of the Sea (ICES) in 1902, countries have become aware of the need to cooperate in order to effectively research and manage shared natural resources. Since those days, a vast array of regional fishery management organizations or arrangements have been established. These usually serve as a gateway between the global and national fishery governance levels for implementing the international fisheries legal system, either through "soft law" instruments such as declarations, assertions of principles, codes of conduct, or international plans of action, or through "hard laws" that are legally binding and enforceable. "Hard laws" include international agreements and conventions that stipulate explicit rules governing State conduct over fisheries (Aqorau 2001).

Global experience has shown that unregulated fishing inevitably results in overfishing. Over-exploited fish stocks must be given time to rebuild to sustainable levels and the regional management of the resources should guarantee an integrated approach to maintain populations. Policies should therefore address the causes of overfishing and the related short-term social and economic adjustment costs, without hurting trade or limiting the rightful and sustainable use of the resource.

Social pressure, from fishing communities and consumers alike, has put the management of human activity in context. The effects upon the marine environment and the sustainability of the resource has created a far greater understanding of the links between fishing, aquaculture and ecosystems. The research needed to provide this understanding is extensive and expensive. In the meantime, policy decision-makers must increasingly take into account the environmental dimension of fisheries management and aquaculture policy development. This strategy is a fundamental part of sustainable development in the fisheries sector. 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 have changed significantly in recent decades. Traditional low-intensive methods with low input levels and relatively small habitat modifications have moved towards modern intensive tank and cage-based techniques. These systems require highly concentrated input levels, significant targeting of species and stocks, and potentially have high impact levels at environmental and social levels.

A common problem in regulating the capture-based aquaculture industry, which is operating in many locations, has been the inadequacy of existing legislation to properly control its expansion. There are potential conflicts of interest with other resource users and activities in coastal areas. Rapid expansion of the sector, coupled with poor regulatory measures, has become a constraint within the industry itself. There is a need for better capture-based aquaculture management; the processes of translating actual or potential impacts into direct environmental costs and into environmental and resources management policies requires development.

Fisheries management

Within the fisheries management process (FAO 1997d), resources management requires considerable information on the biological characteristics, life-cycles, recruitment dynamics, habitat requirements, and fishery interactions for each exploited species. Marine fisheries management should ensure not only that wild populations of these fish are sustained at commercially viable levels, but also that market demands and the economic needs of fishermen are met, while harvest levels are adapted to cope with changing resources abundance. Unfortunately, when little information is available about the status of a stock and its associated fisheries, potential problems tend to be ignored. As a result, most fisheries, both in developing and developed countries, are thought to be either heavily exploited or over-exploited. Many stocks have now been reduced to 10-30% of their original biomass (FAO 2000; ICLARM 1999a,b; Williams 1996).

Some management methods for fish stock assessments are based on catch-at-age data (Coleman *et al.* 1999). The data is used in Virtual Population Analysis (VPA) to reconstruct cohort-specific stock abundance and fishing mortality rates on the basis of past catches. The outcome of the VPA is then used to make annual recommendations for the Total Allowable Catch (TAC). The greatest problem with VPA is that it provides only hindsight information on cohorts that have passed through the fishery, but none on the cohorts that need managing (Coleman *et al.* 1999). Incorrect estimates would not reflect the real condition of the stock, and could lead to management actions that have a negative effect on both the species and the fishing industry. Recruitment forecasting allows management to anticipate problems and to take preventive measures to relieve fishing pressure (Koenig and Coleman 1998).

The cross-disciplinary nature of fisheries management with clear ecological, economic and social dimensions is likely to make solution finding a continuing topic of debate in the coming years. The economic and social aspects of fisheries management can in fact have a severe impact on the choice of management regime and the rigour with which it is imposed (Hall 1999). The conventional management methods used at national and regional level include the following (Jennings, Kaiser and Reynolds 2001):

- Catch controls: these are intended to control fishing mortality by limiting the weight of catch that fishers can take. They include total allowable catch (TAC) or quotas (Q) which are limits on the total catch to be taken from a specified stock (Figure 143), as well as individual quotas (IQ) and vessel catch limits where the TAC is divided between fishing units. Catch controls are amongst the most widely used management regulation. IQs restrict the catches of individual fishers or boats. The sum of all IQs will equal the TAC. If IQs can be bought and sold by fishers than they are known as individual transferable quotas (ITQ). TACs are set to meet the target levels of fishing mortality determined by stock assessment. They may be fixed, or they may change from year to year because fish stock fluctuates and the future is unpredictable. In order to adjust catches from year to year, the government or regulatory authority may buy and sell ITQs.
- Effort controls: these limit the number of boat or fishers who work in a fishery, the amount, size and type of gear they use, and the time that the gear can be left in the water. Effort controls may also limit the size or power of vessels and the periods when they fish. The aim of effort control is to reduce the catching power of fishers and thus reduce fishing mortality. Effort control can be divided into licences, individual effort quotas (IEQ) and vessel or gear restriction. Limited licences restrict the number of boats or fishers in the fishery. Licences can be transferable. Effort quotas limit the amount of

time spent working by a given unit of gear, a vessel, or a fisher. An individual transferable effort quota is a tradable IEQ. Vessel or gear restrictions try to limit the catching capacity of vessel or fishers. These may control the size and the design of pots or nets or the dimension of a fishing vessel, or may ban specific gears that are seen as too effective.

→ Technical measures: these restrict the size and sex of fished species that are caught or landed, the gears used and the times when, or areas where, fishing is allowed. The size of individuals that are landed may be controlled by minimum landing sizes (MLS). Time and area closures can protect fished species at specific phases of their life history. Examples are the protection of juvenile nursery areas or adult spawning grounds. Time closures can protect annual stocks until their production and quality is high, but also lead to market gluts at the start of the fishing season. Time and area closures have been most effective when used in conjunction with other measures such as catch and effort controls.

Figure 143. Fishing bluefin tuna for capture-based aquaculture in the Mediterranean (an example of quota regulated fisheries) (Photo: F. Ottolenghi)

National and regional fishery management

According to the Code of Conduct for Responsible Fisheries (FAO 1995), conservation and management measures, whether at local, national, sub-regional, or regional levels, should be based on the best scientific evidence available and designed to ensure the long-term sustainability of fishery resources. The measures used should promote a rational exploitation, possibly below MSY, while maintaining the availability of the resource base for present and future generations. Within fisheries under national jurisdiction, States should identify the relevant domestic parties having a legitimate interest in the use and management of fisheries resources and seek their cooperation in achieving responsible fisheries.

For stocks exploited by two or more States (either transboundary, straddling or highly migratory fish stocks) there needs to be cooperation to ensure effective conservation of the resources and management of the fisheries. This should be achieved by the setting up of bilateral, sub-regional or regional fisheries organizations or arrangements. A sub-regional or regional fisheries management organization or arrangement should possibly include States under whose jurisdiction the resources occur, as well as States which have a real interest in the fisheries even though the resources are outside their national jurisdiction. States and sub-regional or regional fisheries management organizations and arrangements should ensure that the laws, regulations and other rules governing their implementation are accepted by all parties (FAO 1995).

Many regional fishery bodies foresee a two-tiered structure; in this concept a scientific entity, either a subsidiary or an independent body, provide scientific advice to the regional fisheries management organization. Indeed, there are two different approaches to developing scientific advice. One approach is based upon a "science secretariat", with has its own independent staff. The Oceanic Fisheries Programme (OFP), the IATTC (Inter-American Tropical Tuna Commission), the NAFO (Northwest Atlantic Fisheries Organization) and others utilize this system. However, the majority of the Regional Fisheries Management Organizations rely on a "multinational approach", where scientists from different national institutes of the Member States meet regularly to develop and agree on scientific advice as instructed by the management body.

The source and availability of staff is the key feature that distinguishes science secretariats (independent staff) from multinational approaches (national scientists) and that may influence the nature of the advice, because compromises are most likely to occur at an early stage in the second approach. The ICCAT (International Commission for the Conservation of Atlantic Tunas), the GFCM (General Fisheries Commission for the Mediterranean), CITES (Convention on International Trade in Endangered Species) are examples of such "multinational" scientific approach that are widely utilized. This approach tends to predominate, because Member States prefer an approach that has low up-front costs and secures their individual, immediate and direct involvement in the fishery's scientific research and subsequent input to management (Ward, Kearney and Tsirbas 2000).

In both cases, the monitoring and state of the resources can be compromized where important fishing nations are not parties to the Regional Fisheries Management Organization or arrangement. Difficulties may also occur where fishing activities outside the jurisdiction of an authority take targeted or incidental catches of species that are under the responsibility of the administration, as is the case of some highly migratory stocks, e.g. bluefin tuna in the Mediterranean and North Atlantic.

Bluefin tuna management – an example for capture-based aquaculture

Two examples of the regional management of capture-based aquaculture, both of tuna, are provided in this section of the report; regional organizations with a remit that includes tuna are listed in Table 78.

The southern bluefin tuna and the CCSBT

The first example is provided by the Commission for the Conservation of Southern Bluefin Tuna (CCSBT), which has the responsibility for the management of the stock. Since 1985, Australia, Japan and New Zealand have met to negotiate annual global quotas for southern bluefin tuna (Figure 144). Since 1994, these negotiations have been under the auspices of the CCSBT (1994) and involve the setting of an annual TAC and the negotiation of national allocations (quotas) within that TAC. Each year, discussions on allocation are preceded by a scientific meeting involving scientists from the three Member countries, who exchange scientific data and provide an assessment on the state of the stock. Increased scientific effort has been warranted, given the massive decline in catch but it took several years to reach agreement. Since 1990 there has been a strict annual quota of 11 750 tonnes (Haward and Bergin 2001) of which each Member has been allocated a constant share (Japan: 6 065 tonnes; Australia: 5 265 tonnes; New Zealand: 420 tonnes). The Republic of Korea and Taiwan Province of China became active in the CCSBT in 2001 and 2002 respectively; for the 2003-4 season they were each allotted catch limits of 1 140 tonnes, while the limits for the other countries remained the same. This compares with the peak output of the southern bluefin tuna fishery of 81 000 tonnes in 1961, before stringent quota reductions were applied to prevent stock collapse. The southern bluefin tuna population today is thought to be so severely depleted that the Convention for International Trade of Endangered Species (CITES) has listed the species as “critically endangered” in its “Red List” of endangered species.

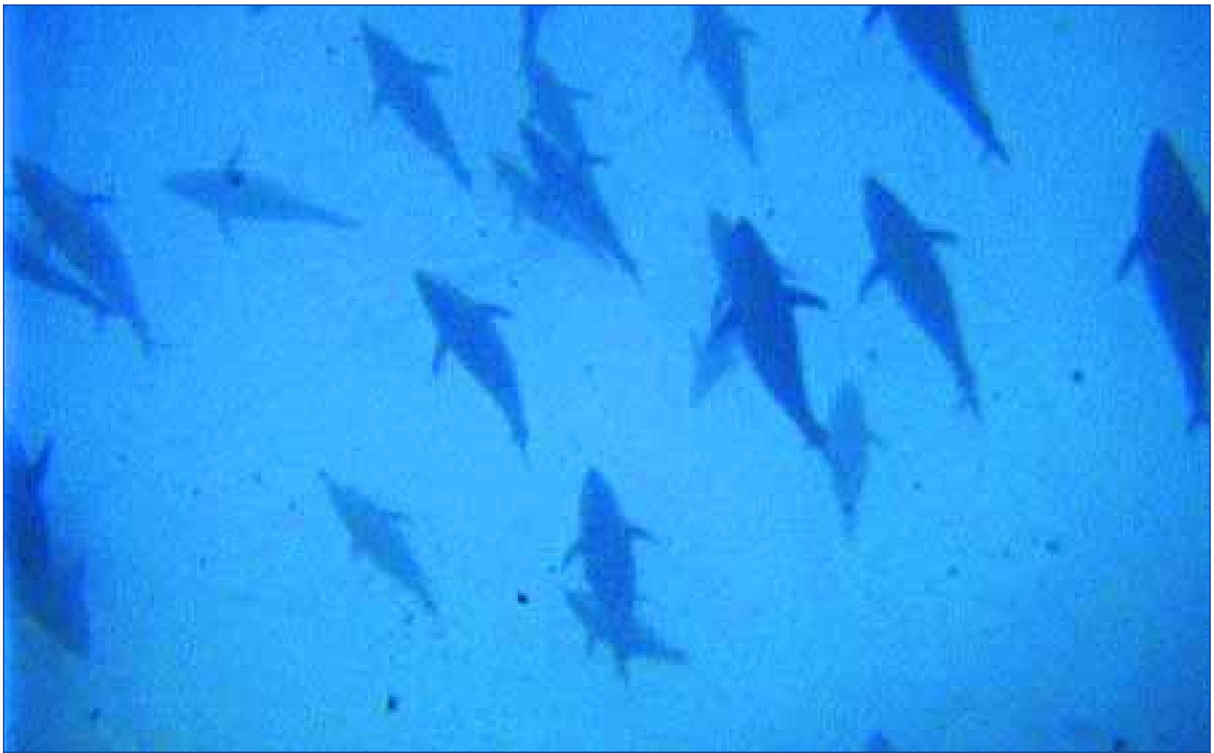


Figure 144. Southern bluefin tuna *(Thunnus maccoyii)* (Photo: L. Mittiga)

CCSBT has also introduced a trade information scheme to track the point of origin of southern bluefin tuna. This proposal had been mooted for several years, following the introduction of a similar scheme by ICCAT. In addition, a southern bluefin Statistical Document Programme (SDP) was launched in June 2000 (Haward and Bergin 2001). It includes the principle that “there is no waiver” of the requirement that all imports of southern bluefin tuna into the territory of a

Member of the CCSBT shall be accompanied by a CCSBT Southern Bluefin Statistical Document. The scheme is also based on the principle that the programme will conform to "relevant international obligations". One of the interesting elements where information is required is for capture-based farmed tuna, thus taking into account the significance of farmed southern bluefin tuna in Australia. As in other schemes, an official of the each vessel's flag State, or its "delegated entity", endorses the Southern Bluefin Statistical Document that accompanies the landing of the fish. Data obtained from the programme is then forwarded to all Members twice a year. Members then check export statistics against the data provided to them from the CCSBT Secretariat.

It should be noted that, following the explosion of tuna capture-based aquaculture, the quota of one Member (Australia) was year by year completely utilized by the farming industry until the CCSBT imposed a cap on the maximum amount of juvenile catch to be taken for this purpose. The southern bluefin tuna collected by the fishery and transferred to the capture-based aquaculture system are monitored by the Federal Fishery Management Authority (that administers the wild fishery), which estimates the total live tuna collected for farming by each operator and deducts it from its TAC.

The northern bluefin tuna and the ICCAT

The second example is provided by the Atlantic and Mediterranean[1] large pelagic fisheries that are under the competence of the International Commission for the Conservation of Atlantic Tunas (ICCAT), which was established in 1969 with the aim of coordinating international research and management of highly migratory tunas and billfish in the Atlantic and adjacent waters. ICCAT is currently composed of 32 members and is endowed with a Standing Committee on Research and Statistics (SCRS) that provides scientific advice to the Commission, The SCRS conducts stock assessments of Atlantic tunas and billfish and coordinates multinational research activities related to these species. The stock assessments, upon which the Commission bases its decisions, change from year to year in response to improved methodologies and revised statistics.

ICCAT's primary stated bluefin management goal is to maintain Atlantic bluefin tuna populations at levels that will allow the Maximum Sustainable Yield (MSY). The MSY is an estimate of the greatest average catch that can be removed from fish stocks year after year, without reducing the stock's ability to sustain these maximum catches in subsequent years (Buck 1995). In an effort to achieve this aim, ICCAT recommended a number of management measures for the Western Atlantic bluefin fishery, which included harvest quotas, per trip catch limits, and a minimum size limit (currently 6.4 kg).

In 1981, ICCAT decided to manage the Eastern and Western Atlantic bluefin tuna stocks as discrete populations, setting a conventional boundary at 45°W. This two-stock hypothesis is supported by the presence of small to large specimens on both sides of the Atlantic, the occurrence of spawning in the Gulf of Mexico and the Mediterranean at different times of the year, and morphometric differences between fish from different areas. Analysis of conventional tagging data, which show a low fish-mixing rate with most tags recaptured in the area of release, also gives support to the existence of two separate groups of bluefin tuna in the North Atlantic (Arnold *et al.* 2003). Several electronic tagging programmes have been initiated recently; these include experiments with "pop-up" satellite-detected tags carried out in Europe between 1998 and 2000 (Arnold *et al.* 2003) and in Canada and New England since 1997 (Lutcavage *et al.* 2003). Additional research is needed for a better understanding of tuna biology, including the

1 In the Mediterranean, large pelagic fisheries are also under the competence of the General Fisheries Commission for the Mediterranean (GFCM). GFCM and ICCAT have established a Joint Working Party to monitor the status of tuna and tuna-like species.

movements of reproductive habitat and spawning site fidelity. There is also a need for a genetic survey of the bluefin tuna and its Mediterranean and Atlantic distribution to understand if mixing occurs between the two stocks; some results are already available, and various studies are currently in progress (Magoulas 2002; Pla 2002).

In 1981, ICCAT initiated a stock recovery plan for the Western Atlantic bluefin population. The Commission recommended that the scientific monitoring quota should be as low as possible for the Western Atlantic and this was set at 1 160 tonnes for the 1982 fishing season in the Western Atlantic but was increased to 2 660 tonnes for 1983 (Buck 1995) and remained at this level until 1992. Between 1993 and 2001 the quota, which is revised at two-yearly intervals, ranged between 1 995-2 500 tonnes. Current catches from the western stock are modest, but the stock is still considered as over exploited (Tudela 2002b). ICCAT also developed a management regime for the eastern stock and the MSY was set at 29 500 tonnes for the Eastern Atlantic and the Mediterranean, with quotas (TACs) allocated on a State by State basis. The 1998 stock assessment for the Eastern Atlantic bluefin tuna, as analysed by the SCRS, showed that breeding population levels had declined alarmingly.

Capture-based tuna farming now complicates the stock assessment in the Mediterranean area, due to the transhipments of tuna "at sea". In the Mediterranean, owing to the absence of EEZs, the stock has the potential for much greater common ownership, and this gives rise to conflicting data. The main problem is that it necessary to know the characteristics of the fish when they are first caught (size, location, fleet/gear used, and the amount of fishing effort spent in capturing them) (ICCAT 2003). Biological sampling is necessary to understand the age and structure of the populations. Today it is more difficult to know the precize biological composition of a catch, since tuna are not landed to local buyers but are transferred live at sea. There, the counting of the fish is often done by divers equipped with underwater cameras to estimate fish length and the size composition of the catch (giving total weight). However, the results are still crudely estimated.

Capture-based tuna farming has raised other issues, due to the lack of information on growth and conversion rates in cages, data that is required for the BTSD to back-calculate weight at catch. The challenge is to ensure that the tuna catches sold to tuna farmers are reported for both stock assessment and quota purposes. The difficulties related to collating the data received from most of the Mediterranean tuna farms and national authorities in 2001 has led ICCAT to estimate that tuna gain an average of 25% of their body weight during the farming period. This has led to a conversion factor of 0.8 that is applied to farmed products imported by Japan, which is used to back-calculate the weight of the catches before the capture-based aquaculture period.

ICCAT introduced a Bluefin Tuna Statistical Document (BTSD) programme for frozen bluefin in 1993 and for fresh bluefin in 1994. The aim of the programme was to increase the accuracy of bluefin statistics and track unreported fish caught. The programme requires that all contracting parties must report all imported bluefin tuna, and that these records are accompanied by an ICCAT BTSD detailing the weight and type of products by flag of the fishing vessels and area of fishing operations (Miyake *et al.* 2003).

There is general agreement that capture-based aquaculture should be developed within a Best Management Practice framework. For this purpose GFCM and ICCAT established a Joint *ad-hoc* Working Group on Sustainable Tuna Farming Practices in the Mediterranean in 2002. The Working Group is composed of scientists from the GFCM Scientific Advisory Committee and the GFCM Committee on Aquaculture, and of scientists from the ICCAT SCRS.

Table 78. Examples of regional organizations with remits that include tuna (Ward, Kearney and Tsirbas 2000, modified; FAO 2003)

Acronym	**GFCM**
Organization	General Fisheries Commission for the Mediterranean
Founding year	1949
Membership	Albania, Algeria, Bulgaria, Croatia, Cyprus, EC, Egypt, France, Greece, Israel, Italy, Japan, Lebanon, Libya, Malta, Monaco, Morocco, Romania, Slovenia, Spain, Syria, Tunisia, Turkey
Species	All species including tunas and small tunas
Area of competence	Mediterranean Sea, adjacent waters, the Black Sea and the Azov Sea
Main functions	To promote the development, conservation and management of living marine resources; to formulate and recommend conservation measures; to encourage training cooperative projects
Approach to science	Multinational

Acronym	**IATTC**
Organization	Inter-American Tropical Tuna Commission
Founding year	1949
Membership	Costa Rica, Ecuador, El Salvador, France, Guatemala, Japan, Mexico, Nicaragua, Panama, Peru, USA, Vanuatu and Venezuela
Species	Tuna, tuna-like species, dolphin
Area of competence	Eastern Pacific Ocean
Main functions	To gather and interpret information on tuna; to conduct scientific investigations; to recommend proposals for joint action for conservation
Approach to science	Science secretariat

Acronym	**ICCAT**
Organization	International Commission for the Conservation of Atlantic Tunas
Founding year	1969
Membership	Algeria, Angola, Barbados, Brazil, Canada, Cape Verde, China, Côte d'Ivoire, Croatia, Equatorial Guinea, EC, France (St. Pierre and Miquelon), Gabon, Ghana, Guinea Conakry, Honduras, Japan, Korea (Rep. of), Libya, Mexico, Morocco, Namibia, Panama, Russia, Sao Tomé and Principe, South Africa, Trinidad and Tobago, Tunisia, UK (Overseas Territories), United States, Uruguay and Venezuela
Species	Tuna and tuna-like species
Area of competence	Atlantic Ocean including the adjacent seas
Main functions	To study the population of tuna and tuna-like fishes; to make recommendations designed to maintain these populations at levels permitting maximum sustainable catch
Approach to science	Multinational

Acronym	**FFA**
Organization	South Pacific Forum Fisheries Agency
Founding year	1979
Membership	Australia, Cook Islands, Federal States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, New Zealand, Niue, Palau, Papua New Guinea, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Western Samoa
Species	Tuna
Area of competence	South Pacific (Central and West)
Main functions	To harmonize fishery management policies; to facilitate cooperation in surveillance and enforcement, processing, marketing and relations with third countries; to arrange for reciprocal access by member countries to their respective 200-mile zones
Approach to science	Multinational

Acronym	**IOTC**
Organization	Indian Ocean Tuna Commission
Founding year	1993
Membership	Australia, People's Republic of China, Comoros, Eritrea, EC, France, India, Iran, Japan, Korea (Republic of), Madagascar, Malaysia, Mauritius, Oman, Pakistan, Seychelles, Sri Lanka, Sudan, Thailand, UK
Species	Tuna and tuna-like species
Area of competence	Indian Ocean and adjacent seas north of the Antarctic Convergence
Main functions	To promote cooperation in the conservation of tuna and tuna-like species and also promote their optimum utilization, and the sustainable development of the fisheries
Approach to science	Multinational

Acronym	**CCSBT**
Organization	Commission for the Conservation of Southern Bluefin Tuna
Founding year	1994
Membership	Australia, Japan, New Zealand
Species	Southern bluefin tuna
Area of competence	Atlantic, Pacific and Indian Oceans where SBT are found
Main functions	To collect, to analyse and interpret scientific and other relevant information on SBT to adopt conservation and management measures including the total allowable catch and its allocation among the Members
Approach to science	Multinational

Acronym	**WIOTO**
Organization	West Indian Ocean Tuna Organization
Founding year	1991
Membership	Comoros, India, Mauritius, Seychelles
Species	Tuna and tuna-like species
Area of competence	Western Indian Ocean
Main functions	To harmonize polices with respect to fisheries; to determine relations with distant water fishing nations; to establish mechanism for fisheries surveillance and enforcement; to cooperate in fisheries development; to coordinate access to EEZs of the Members
Approach to science	Multinational

The southern and northern bluefin tuna populations are examples of capture-based aquaculture target pelagic species. They are highly migratory and, being a shared resource, responsible management requires common rules, which need to be adopted and properly enforced in all the distribution areas of each species. ICCAT, GFCM and CCSBT face many complexities and difficulties in order to improve their management, and specific new rules have to be implemented to deal with the tuna capture-based aquaculture issue. The high economic value of the species and market interests will inevitably make solutions challenging.

Aquaculture management

Marine finfish aquaculture is a relatively recent phenomenon that has experienced the bulk of its growth over the last three decades. Asia is the leading continent, with a long history of small-scale marine farming, a labour-intensive activity that was well integrated with the local environment and within the bounds of available resources. During the last 30 years it has grown into a large-scale food producing industry, which is now focused on earning foreign currency from exports. The rapid expansion of intensive monoculture systems has led to developments in the sector where the focus has been on raising predominantly carnivorous, highly profitable species that demand large amounts of feed, water and fertilizers. This pattern of expansion has been witnessed worldwide. Intensive marine aquaculture, together with the exploitation of other marine resources, the expanding coastal population, urban and agricultural pollution, capture fisheries, tourism, and recreational industries have all increased the pressure on the world's coastal ecosystems.

Nowadays, there is a general realization that for aquaculture to be sustainable, management must not only be aware of the technological issues but also understand the environmental effects, as well as socio-economics issues and markets. Intensive aquaculture, particularly when dependent on fishmeal for the feeding of carnivorous species, is the form of farming most questioned in terms of sustainability (Folke, Kautsky and Troell 1994, 1997; Naylor *et al.* 1998, 2000). Aquaculture is considered a source of potential danger to coastal ecosystems, when it is not managed correctly. Aquaculture management must be included as part of an Integrated Coastal Management (ICM) plan. The concept of ICM was developed in the 1990s, and has been widely embraced around the world. The management of capture-based aquaculture must now be viewed within this environmental concept, and the influence of ICM policies on it are increasing.

A practical consideration for managing aquaculture within the ICM environment is the consideration of environmental carrying capacity, which for aquaculture can be defined as the level of production that a given area (water body) can accommodate without causing significant impacts to the surrounding environment or other resource users (Donnan 2000). GESAMP (1986) defined this capacity as "a property of the environment and its ability to accommodate a particular activity or rate of an activity ... without unacceptable impact".

More specifically, in terms of biological and chemical parameters, GESAMP (1996) defined environmental capacity as:

- the rate at which nutrients are added without triggering eutrophication;
- the rate of organic flux to the benthos without major disruption to natural benthic processes;
- the rate of dissolved oxygen depletion that can be accommodated without mortality of the indigenous biota.

As ICM programmes are established on a long-term basis, there are a few examples of the application (with aquaculture as a factor) that can be used (Table 79).

Table 79. Some ICM programme applications

Country	Legislative	Year	Content
Australia	National Strategy for Ecologically Sustainable Development	1992	Integration of economic, social and cultural ocean uses
	National Strategy for the Conservation of Australia's Biological Biodiversity	1996	
	Australia's Ocean Policy	1998	
Canada	Ocean Act	1997	Precautionary approach and sustainable development for oceans strategy
European Community (EC)	Report on CZM and demonstration programme on 35 ICZM projects (EC 1999).	1999	Need for aquaculture/fisheries policy to be integrated with the environmental policy
Indonesia	Act n. 5/1990 Presidential Decree n. 32/1990	1990	Protection of fish habitats (coral reefs, mangroves, sea-grasses) Management of protected areas
New Zealand	Resource Management Act. Besides, a wide ranging review and report on coastal issues (PCE 2000)	1991	Integrated planning framework for aquaculture

Major international initiatives for ICMs are the adoption of Chapter 17 (oceans and coasts) of the Rio de Janeiro 1992 Agenda 21 (www.un.org/esa/sustdev/agenda21.htm), Articles 9 (aquaculture development) and 10 (Integration of Fisheries into Coastal Area Management) of the FAO Code of Conduct for Sustainable Fisheries (FAO 1995), and, more particularly for aquaculture management, the development of a series of Coastal Zone Management (CZM) systems around the world. The main points contained in the 2002 Johannesburg plan (www.johannesburgsummit.org) are related to the promotion of the "ecosystem approach" for the protection of marine biodiversity, and from the beginning of 2004, a monitoring system which evaluates the marine environment. The main goal for fisheries is the adoption of strategies and measures necessary to generate sustainable fisheries by 2012.

Despite their theoretical advantages, the more comprehensive (National, Regional) forms of ICM are unlikely to offer an effective solution to the immediate needs of improved planning and management in the areas of existing, or rapidly developing coastal aquaculture activities.

National and Regional aquaculture management

There is no single planning or management framework tool that can be universally applied to promote more sustainable coastal aquaculture development. The importance of legal, procedural and planning frameworks designed to facilitate sustainable aquaculture development is emphasized in the Code of Conduct for Responsible Fisheries (CCRF) (FAO 1995). This promises to have a significant impact worldwide on the development of regulatory systems for aquaculture in the coming years. Article 9 of the CCRF deals with aquaculture development and sets out a wide range of relevant principles and criteria. The first principle is that States should establish, maintain and develop an appropriate legal and administrative framework which facilitates the development of responsible aquaculture. FAO has also produced technical guidelines for responsible aquaculture development (FAO 1997b), which are intended to provide general advice to support and implement Article 9 of the CCRF.

Progress has also been made in the application of the hazard analysis critical control points (HACCP) system in aquaculture (see also the following chapter) and FAO has published general guidelines for seafood quality (Huss 1993). In addition, FAO is currently involved in reviewing the draft Code of Hygienic Practice for the Products of Aquaculture under the auspices of the *Codex Alimentarius* Committee on Fish and Fishery Products. This Code deals with key hygienic factors involved in all aspects of finfish and crustacean farming, from location and layout of aquaculture facilities to end-product specifications and the production of an HACCP system. The Code is advisory in nature and is intended to be used as a guideline for preparing national quality standards and fish inspection regulations by countries that do not possess fully-developed legal regulations (De Fontaubert, Downes and Agardy 1996).

In many countries laws regulating aquaculture are poorly developed and frequently consist only of a few articles pertaining to capture fisheries legislation. However, during the last few years there has been a growing interest in many countries to develop a comprehensive regulatory framework for aquaculture that will protect the industry, the environment, other resource users and consumers (New 1999). While capture fisheries are generally regulated by a single government department, aquaculture is frequently regulated by many agencies under a variety of laws. This means that developing a comprehensive regulatory framework for aquaculture is often a legally and institutionally complex process. Often it involves drafting or amending legislation that addresses a variety of issues, e.g. land use planning and tenure; water extraction, use and discharge quality; fish movement; disease control and notification; pharmaceutical use; and food quality and public health. It also requires the establishment of institutional arrangements to ensure the co-operation and co-ordination of many different institutions with jurisdiction over natural resources, animal and public health, environment, etc.

Although new comprehensive national laws that regulate aquaculture may be desirable in many countries, other options are now being considered. Developing and passing new legislation is a long process and sometimes takes several years, while the rapid development of the sector has created an urgent need for regulation. These options include the enactment of regulations under existing legislation, and non-legally binding agreements such as guidelines and codes of practice. For example the EU has over 250 different regulations that can apply to fish farming.

Capture-based aquaculture transcends both aquaculture and fisheries legislation. As the sector develops there are likely to be greater areas of conflict and more difficulties for this sector, due to increased legislation in both the fisheries and aquaculture sectors. Capture-based aquaculture needs the development of "soft law" instruments, economic incentives and performance bonds, as well as requirements for international and regional collaboration.

Environmental Assessment (EA) – a technical instrument for aquaculture management

Environmental Assessments (EAs) or Environment Impact Assessments (EIAs) could represent a sound technical approach for the development of sustainable aquaculture management systems, and should be compulsory for all new aquaculture developments. In many cases, where international finance or grants are involved, the sponsor will be required to undertake an EA. The EA is normally part of the feasibility study, and is essential to obtain investment funding. The management of each project needs to develop a monitoring system from the EA, in addition to other mitigation measures, in order to ensure the continuing sustainability of the project in environmental terms.

Capture-based aquaculture presents a series of environmental impacts that need an EA and monitoring system, since this would help to prevent conflicts between coastal users, protect sensitive habitats and improve sustainable development of the mariculture industry. At a national level, where an EA regulation exists, licenses for aquaculture sites are more or less mandatory. These are granted only following the presentation of an Environmental Impact Statement/Study, which is the technical basis for local decision makers (who will take into account other factors including public opinion, private sector/producer associations, environmental organizations, various NGOs, etc.). Table 80 shows some examples of EA national legislation worldwide.

An aquaculture proposal has to satisfy several characteristics that take into account all potential environmental hazards: impacts on the ecosystem (water, sediment, habitats, pelagic components,

Table 80. Environmental Impact Assessment Acts

Country	Legislative	Year	Content
Indonesia	Environmental Management Act (EMA)	1982	Environmental protection and management
	Analysis of Impact on the Environment (AIE)	1986	Enabling regulation of EMA
Malta	Policy and Design Guidance for EIA	1994	Technical guidelines for EIA and EIS
Sweden	Swedish Environmental Code	1999	Sustainable development

benthos, other organisms), stock removal, visual impacts (on the visual amenity of the site), odours, noise or vibrations (tourism may decrease due to odours caused by tuna farms, as has happened in Croatia), human health and socio-economic effects.

Mitigation measures have to be included in the EA to prevent or to minimize such impacts. Surveillance monitoring (long-term), site specific monitoring (medium-term) and operation compliance monitoring (short-term) represent important mitigation measures (Figure 145). Management needs to develop contingency plans for the operation, so that if an undesirable impact is detected, alternative operating policies and practices are on hand and the project does not have to cease functioning.

Figure 145. Capture-based Japanese amberjack culture in Japan: monitoring is a tool to assess its sustainability (Photo: M. Nakada)

Aquaculture – specific legislation

In the Mediterranean, there are several legislative instruments governing marine aquaculture activities. For example, Dosdat and de la Pomelie (2000) show that operators in France are regulated by a law that still has to be harmonized with EU directives. Fish farmers have to obtain a permit for the use of maritime public property and an operating authorization, as fish farming is considered by law to be an “activity liable to pollute”. The permit lists the species to be farmed, production levels, culture system, location and some other general specifications of the operation. Farmers have to pay a fee that depends on the size of the activity (e.g. € 8.40 per 100 m^2 area, for fish) and not on the actual production value. The authorization consists of an ordinary declaration for a fish production below 20 tonnes per year, and an implemented authorization if this threshold is to be exceeded. This regulation was applied to marine fish farming in 1993. The central document is the Environmental Impact Study (EIS), and the monitoring of aquaculture impacts is undertaken by the Departmental of Veterinary Services (DVS). The most common monitoring scheme for sea-cage farming involves a survey of the benthos (redox potential, benthic fauna, settled organic matter) carried out every six months, a water nutrient analysis (near-shore to the cages) and microbiological monitoring at 3 monthly intervals. Fish farmers have to record every intervention and farming activity (standing stocks, food consumption and ratios, input-output of fish, etc.), accidental mortality and losses, waste management (dead fish, organic matter, fuel) in a report transmitted to the DVS. The use of veterinary products is regulated by EU directive 92/18 (antibiotics, food additives and vaccines) (Dosdat and de la Pomelie 2000).

The above requirements are also needed as part of an HACCP system (see the following chapter) and, although adding to the operating costs of the project, these controls and reporting systems have the potential to add value and assure consumers. The term “environmentally sustainable and responsible aquaculture” is becoming an important “tag” for serious commercial companies.

At both national and local levels there is a lack of standardization. For example the threshold in Ireland is set at 100 tonnes compared to 20 tonnes in France, while in Italy the limit is related to area, not to the production method or density (5 ha for intensive farming). Site choice is also difficult to standardize, due to the local characteristics of coastal zones, which differ greatly from place to place. It is also very difficult to establish a set of effluent standards for open water cage farming systems.

Legislation should aim to regulate fish density, depending on carrying capacity, in order to minimize the environmental effects of fish farming. These effects can be significantly reduced by careful site selection, site carrying capacity assessment, stock density control, and improved feed formulation (artificial feed instead of trash fish). Use of trash fish as fish feed is being regulated in some countries: in Denmark, trash fish has been banned and fish farms have been forced to switch to formulated feeds. Compared with pelleted feed, the use of trash fish leads to a much higher wastage of feed. Research conducted on Hong Kong grouper culture showed that solid wastes could be reduced by 5 433 tonnes (40%) (Chu 1999). Feed wastage is a function of protein intake and the digestibility of the feed (percentage of non-digestible components present), and can be reduced by improved feed technology. For example, ammonia excretion by fish is a function of nitrogen and protein intake (Engin and Carter 2001) and can be kept to a minimum with artificial feed. The levels of nitrogen and phosphorous in feed have decreased, as artificial feed matches more closely the dietary requirements of fish. Modern diets tend to contain more lipids and less binders and carbohydrates. This has resulted in a general reduction improvement in feed conversion ratios (Black 2001).

The application of computer modelling to aquaculture management and monitoring should also be carried out to ensure that the culture activity is environmentally sustainable. A numerical model has been developed that describes the material cycling in Japanese amberjack (*Seriola quinqueradiata*) culture grounds, and has been successfully applied at Yusu Bay in the Bungo Channel, Japan (Takeoka *et al.* 1988). The seasonal change in flux of particulate organic carbon in the bottom layer, which consisted of the remainder of the bait and the faecal matter from yellowtail culture, has been calculated using the data and parameters for Yusu Bay. The results fitted well to the flux values of particulate organic carbon into the bottom layer obtained by sediment trap experiments in Yusu Bay.

Grouper management – an example for capture-based aquaculture

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. 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 Food Fish Trade (LRFFT). 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 resolutions have been taken to reduce exploitation: the Bahamian government has recently approved the establishment of five no-take marine reserves. All of these sites contain known Nassau grouper 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).

Other regulations should be developed to control capture-based 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 *et al.* 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 81).

A Southeast Asian survey found that while the quantity of "seed" caught was astonishing, the production level was very low. 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 (Sadovy 2000). 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 directions and initiatives to attain a better use of biological resources 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 and sea-grass environments in river mouths and estuaries, and to ensure "seed" production by safeguarding spawning adults. Marine protected areas may incorporate key settlement and nursery areas.

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

Table 81. Southeast Asia National Regulations (Sadovy 2000)

Locality	Regulation
People's Republic of 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
Hong Kong SAR China	➔ 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 ➔ Scissor nets are illegal ➔ Fyke nets have been banned ➔ The Fisheries Code of 1998 (Republic Act 8550) prohibits the export of "seed" of milkfish and prawns but its application to groupers 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 BFAR
Taiwan Province of China	➔ In Penghu Island, fisheries 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 (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

International Agricultural Research (ACIAR), and the WorldFish Center (formerly known as ICLARM), etc. 1998 saw the establishment of the Asia-Pacific Grouper Network (APGN); this organization aims at 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;
- 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;
- 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 set up 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.

Conclusions

The complex interactions of capture-based aquaculture with fisheries and aquaculture pose many difficulties. There is a need to develop specific rules that complement existing regulations in order to improve management practices. Management schemes for capture-based aquaculture need innovative instruments and concepts. Overfishing, bycatch, gear selection, etc., are common problems concerning resource removal. Environmental impacts (waste, eutrophication, etc.) are problems that are shared with other aquaculture systems. However, in addition, capture-based aquaculture practices have their own specific characteristics, such as "seed" importation, the transhipment of live fish in open seas, the unloading of catches, food quality, unspecific diets for feeding (mostly trash fish), etc. Other complexities are species-specific; some examples are the towing-cage transportation of tuna, the wastage of "seed" arising from unnecessary mortalities during harvest, transport and culture, and the problems linked to the export/import of capture-based "seed".

Most of the concerned management authorities (either at national, sub-regional, or regional levels) having to deal with capture-based aquaculture systems are working to assess the dimension of the issue, in efforts towards identifying adequate responses. For example, at a regional level, ICCAT and GFCM are considering potential solutions to integrate northern bluefin tuna capture-based aquaculture within a coherent management framework in the Mediterranean area. As an example of actions at a national level, the Japanese Coastal Fishing Grounds Rehabilitation and Development Law, enacted in 1974, creates fish shelters to attract fish to new fishing grounds and promotes the release of fry into coastal waters for culture-based fisheries. A fishing rights system authorizes local cooperatives to manage the fisheries in coastal waters, and a special license is required to collect and sell the fry of yellowtails, to prevent overfishing.

With regard to the management of groupers, one possible approach 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 and sea-grass environments in river mouths and estuaries, and to ensure “seed” production by safeguarding spawning adults. Protected marine areas may incorporate key settlement and nursery areas.

For all capture-based farmed species it is important to study not only the biological characteristics (spawning capacity, behaviour, etc.) of both the wild and farmed fish and to carry out specific research, but also to understand all of the impacts and monitor all the parameters related to these practices, particularly the social, economic, and environmental parameters. The need to develop policies and a legal framework for capture-based aquaculture is now widely recognized. As capture-based aquaculture is a practice which is constantly developing (mainly for high commercial market value target species), care should be taken to create or amend the comprehensive regulatory framework to ensure that the sector develops in a sustainable manner. In particular, legal and institutional instruments should continue to be explored and developed, *inter alia*, to:

- recognize capture-based aquaculture as a distinct sub-sector;
- integrate capture-based aquaculture concerns into resource use and development planning;
- improve food safety and quality to safeguard consumers, and meet the standards of importers;
- improve the management of capture-based aquaculture, particularly where the practice is potentially unsustainable (e.g. due to overfishing, bycatch, food wastage, the use of trash fish, and the relationship between the consumption of raw fish and consumer safety).

Specific actions might best be taken through international agreements or arrangements among the countries that share the same resources. Related measures could include acceptable capture methods for “seed” and market-size fish, seasonal or other bans to protect specific size classes or species, and restrictions on numbers and sizes taken. For the responsible management of capture-based aquaculture, it would also be advisable for governments to consult and permanently interact with private farmers, in order to identify factors that may be inhibiting sound management and development; the principles set out in the CCRF and the Draft Code of Hygienic Practice for the Products of Aquaculture could provide useful guidance.

chapter 10

FOOD SAFETY ISSUES

10

FOOD SAFETY ISSUES

Introduction

Most food safety issues are not specific to capture-based aquaculture, or even to the products of any form of aquaculture. However, this report would be incomplete without a general account of the hazards and risks associated with fish production, processing, marketing and consumption, together with an outline of some of the specific risks that may be especially prevalent in capture-based aquaculture products. Therefore, this chapter commences with a description of the risks associated with food, especially seafood consumption. A section on the hazards and risks associated with the products of capture-based aquaculture follows, and the chapter ends with a section on strategies for food safety and quality, including the application of HACCP and environmental certification to capture-based aquaculture products.

Food consumption and associated risks

Hazards that may adversely affect our health are inherent in all human activities, including activities related to food production, such as capture-based aquaculture. Knowledge of the risks associated with seafood consumption is based on epidemiological data that are not always properly understood. The identification of hazards and the determination of their relevance to health, as well as their control, are functions of risk analysis. Risk analysis is an emerging discipline in food safety, and forms the methodological basis for assessing, managing and communicating the risks associated with food-borne hazards. There is a fundamental difference between a hazard and a risk. A hazard is a biological, chemical or physical agent in food, or a condition of food, with the potential to cause harm. A risk is an estimate of probability and severity to exposed populations from the adverse health effects resulting from hazards in food. Understanding the association between the reduction in hazards associated with food and the reduction of risk to consumers is of central importance in the development of appropriate food safety controls (Figure 146).

Figure 146. Food safety controls
(Source: FAO)

All foods can transmit disease, including fish, shellfish and fish products. Food-borne outbreaks are usually defined as the occurrence of two or more cases of a similar illness resulting from the ingestion of common food (Huss *et al.* 2000). In Europe (42 countries), fish, shellfish and fish products were identified as vectors in 5.3% (6th in importance) of the human disease outbreaks investigated in the period 1993-98 (WHO 2001). In other areas problems have been linked to the high consumption of raw fish (which creates further hazards) and of certain potentially toxic species, such as puffer fish, that are highly risky (and whose consumption is forbidden in most countries). These problems can be largely prevented and controlled through appropriate food-safety measures but a number of problems remain, even after the application of Good Manufacturing Practices (GMP), Good Hygienic Practices (GHP), and HACCP principles in the processing of certain types of seafood. For example, there are insufficient controls for monitoring and regulating biotoxins in fish (e.g. ciguatera).

General hazards associated with wild and farmed seafood

The traditional habit of consuming raw (uncooked) seafood in certain countries is an area where prevention of food-borne illnesses is not well developed. The true incidence of illnesses transmitted by seafood is not completely known. Few countries have established reporting systems for seafood-borne illnesses, so data is scarce. Nevertheless, available epidemiological data is useful in demonstrating trends and identifying areas of concern.

Generally, the number of cases resulting from seafood ingestion is small compared to those caused by meat products. However, the importance of seafood as a vehicle for disease depends on a number of factors, such as the diet of the population and the traditional ways of preparing food. In Japan, for example, the proportion of outbreaks due to seafood is high, since fish are an important part of the diet and a lot of fish may be eaten raw. Moreover, in Asia, the custom of eating raw fish leads to food-borne trematode (parasite) infections derived from cultured fish.

The statistics for seafood-borne illnesses show that nearly 80% of all outbreaks related to fish consumption are caused by biotoxins such as ciguatera or scombrotoxin (Huss *et al.* 2000). While the presence of biotoxins in fish is related to certain geographical factors (warm tropical waters), the formation of scombrotoxin (biogenic amines) takes place in specific fish species *post mortem* (such as Scombroidae and Clupeidae) – particularly when these fish are kept at temperatures of >5°C (histamine may also be formed at temperatures below 5°C; it depends on the type of fish flora). Only 12% of seafood-borne outbreaks are due to bacteria (*Clostridium botulinum*, *Escherichia coli*, *Salmonella* spp., *Staphylococcus* spp., *Vibrio* spp., *Bacillus cereus*). Unfortunately, the statistics do not include information on the types of fish products, which were consumed prior to the outbreaks of illness. Knowledge of the safety principles involved in fish processing, e.g. pH, smoke, additives, packaging and preparation before eating (cooked or uncooked products), is useful to evaluate the hazards related to fish products.

The hazards associated with finfish, whether wild or farmed, can be grouped into pre-harvest contamination and harvesting and processing contamination.

Pre-harvest contamination

Pre-harvest contamination mainly involves biological hazards: bacteria, parasites, biotoxins from toxic algae and, to a lesser extent, chemical hazards.

The hazards associated with human pathogenic bacteria in finfish can be divided in two groups: those naturally present in the aquatic environment (referred to as indigenous bacteria) and those present as a result of contamination with human or animal faeces or otherwise introduced into the aquatic environment (Feldhusen 2000). At least ten genera of bacterial pathogens have been implicated in seafood-borne diseases (Figure 147):

- bacteria which are normal components of the marine or estuarine environment (indigenous bacteria) such as *Vibrio cholerae, V. parahaemolyticus, V. vulnificus, Listeria monocytogenes, Clostridium botulinum* and *Aeromonas hydrophila*;

- enteric bacteria which are present due to faecal contamination (non-indigenous bacteria) such as *Salmonella* spp., pathogenic *Escherichia coli*, *Shigella* spp., *Campylobacter* spp. and *Yersina enterocolitica*.

Hazards are relevant or irrelevant according to the risk level at the time of consumption. Indigenous pathogenic bacteria, when present in fresh cultured products, are usually found at fairly low levels and, where these products are adequately cooked, food safety hazards are insignificant. If fish is consumed raw or is not properly cooked the risk can be significant. In Japan, for instance, there are a number of *V. parahaemolyticus* (fish normal flora) outbreaks due to consumption of raw fish.

A few bacteria associated with the faecal contamination of seafood continue to pose a large-scale health threat; these are particularly relevant when culture systems are close to centres of human population, e.g. in Hong Kong. There are also situations where the fish culture system is far from human population and contamination with *Salmonella* spp. may exist. This happens in places where there is a large population of birds (e.g. near the coast); *Salmonella* spp is part of the normal flora of birds, and transfer through their droppings on cages, ponds, etc., cannot be ruled out.

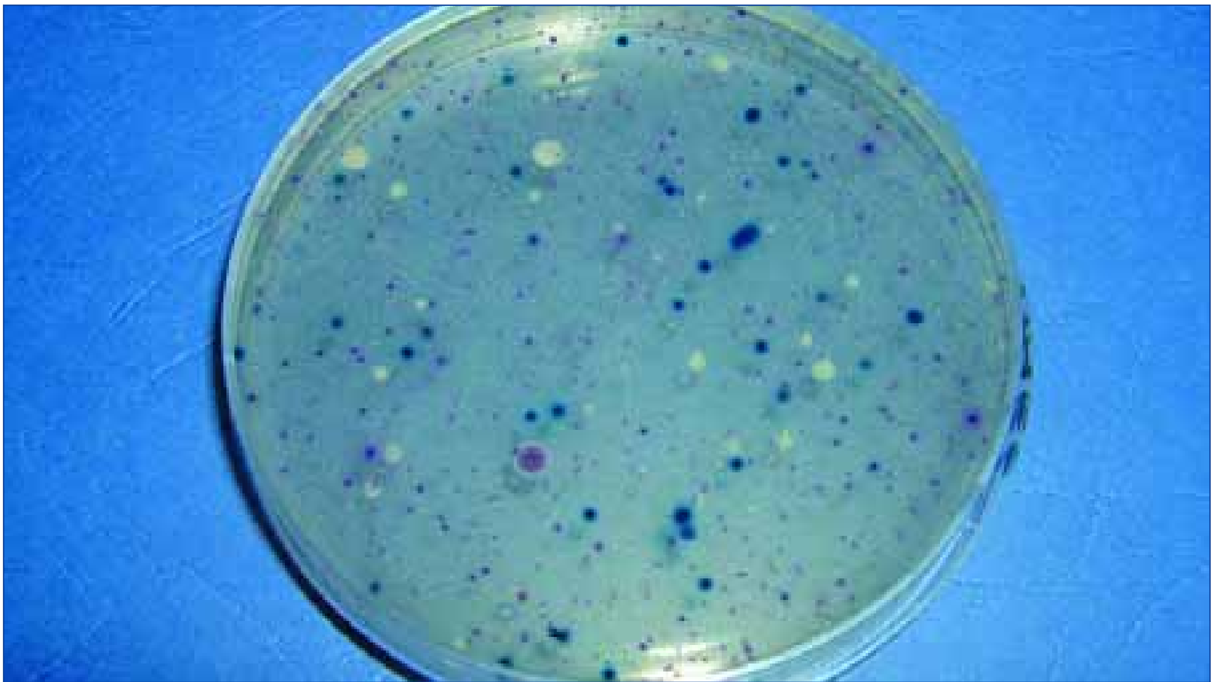


Figure 147. Bacterial seafood analysis (Photo: C. Silvestri)

Live fish may be infected with a number of pathogenic bacteria normally found in the aquatic environment, such as *C. botulinum* and various *Vibrio* spp. However, only the proliferation of these organisms can be regarded as a hazard. The severity of the diseases related to these organisms may be high (botulism, cholera) or low (*Aeromonas* infections), but the likelihood of provoking disease (risk) is very low. Most pathogenic strains require temperatures of more than 5°C for growth and they compete with the normal spoilage flora that proliferate comparatively more rapidly at low temperatures. Thus, products are likely to be spoiled before toxin production or the development of high numbers of pathogens. When products are cooked before consumption, and no further contamination takes place, the risk is largely reduced, as the bacteria and their toxins are heat sensitive (Feldhusen 2000).

In the last 15-20 years there has been an increasing concern worldwide about *Listeria monocytogenes* and its implications for food safety. It has been found in processed seafood products, such as cooked or frozen seafood, marinated fish, "*surimi*", "*sushi*", and smoked fish. The hazard for human health is listeriosis; in Germany there have been an estimated 200 cases per year in a population of 80 million (Feldhusen 2000). At present, there have been no reports of epidemic outbreaks due to this bacteria in the fish products consumed globally; *L. monocytogenes* has been identified as the causative agent in only a few cases. However, the incidence of *Listeria* in fish products is very high in Latin America; in Brazil it was found in domestic and imported seafood, whether raw or ready-to-eat, but the real incidence of *Listeria* is difficult to assess (Destro 2000). Pre-harvest contamination with pathogens from the animal/human reservoir (*Salmonella* spp., *E. coli*) can cause illness but, again, normal cooking procedures mitigate the risk that is related to the consumption of raw fish dishes such as "*sushi*".

Problems related with animal feed ingredients may exist; for example, meat and bone meal (MBM) and animal by-products have been reported to have the highest incidence of *Salmonella*. Chemical or physical pre-treatments substantially decrease initial *Salmonella* population levels in feed protein sources, and have effectively lowered population levels in poultry feed; however *Salmonella* may survive long-term storage (Ha *et al.* 1998).

The presence of parasites constitutes another biological hazard; a large number of fish species can serve as sources of parasitic infections (WHO 1995). In Japan, about five species of parasites affect humans. Among them, the most important is *Anisakis simplex*, which is uncommon in humans since it is killed by normal cooking or freezing of fish products but the consumption of uncooked seafood (e.g. "*sushi*") can cause anisakiasis (Ogawa 1996; WHO 1999). This is especially noticeable in communities where eating raw or inadequately cooked fish is a cultural trait; about 2 000-3 000 cases are reported every year in Japan. The juvenile stage of this parasite infects humans through several cultured fish species.

The most important biological hazards are biotoxins, whose occurrence is widespread. In pre-harvest contamination, ciguatera constitutes the main hazard. Ciguatera is a global problem caused by the consumption of warm-water fish infected with ciguatoxins, a family of heat-stable, lipid-soluble, highly oxygenated, cyclic polyether molecules. They have their origin in *Gymnodinium toxicum*, a benthic dinoflagellate that is at the base of tropical coastal marine food chains (Lewis and Holmes 1993). More than 400 species of fish can be involved in ciguatera poisoning. Ciguatera is mostly confined to the Pacific, Western Indian Ocean and the Caribbean seas; in fact it has a greater socio-economic impact in those regions where fish is the principle source of protein (Lewis 1992). The affects of ciguatera poisoning can last for several weeks or months; gastrointestinal symptoms, such as vomiting, diarrhoea, nausea and abdominal pain typically occur, often associated with neurological problems. Effective treatment of ciguatera requires accurate diagnosis, and intravenous mannitol is a possible treatment. Detecting ciguatoxins is difficult, mostly due to their low levels in ciguateric fish (<0.05 ppb for one common type of ciguatera molecule). Detecting ciguatera is even harder when different classes of these biotoxins coexist, as in Hong Kong where both Pacific and Indian Ocean ciguatoxins occur (Lewis 2000).

The potential hazards due to chemical contaminants in fish and fish products from aquaculture include heavy metals, dioxins, dioxin-like PCBs and similar substances, and residues and unauthorized substances. Heavy metals, such as mercury, cadmium and lead can be tolerated by humans only at extremely low levels. Fish can accumulate substantial concentrations with respect to mercury in their tissues and thus represent a major dietary source of this element. Fish are known to be the largest mercury source, with the exception of direct exposure. The use of chemicals in fish culture is regulated in the USA and in Europe; in some countries regulations may exist but most have no regulatory body to control their use.

Dioxins are mainly a man-made hazard, resulting chiefly from the incomplete combustion of urban wastes. The term "dioxins" is a generic name that encompasses two different types of compounds, the polychlorinated dibenzo-p-dioxin (PCDD) (75 congeners) and the polychlorinated dibenzofurans (PCDF) (135 congeners). Seventeen of these compounds are of recognized toxicological human concern.

Polychlorinated biphenyls (PCBs), also known as "dioxin-like", are a family of 209 congeners, of which about thirteen are of toxicological human concern. PCBs are also a man-made hazard; they were mainly produced for industrial use in electrical equipment (transformers and capacitors). The international treaty on persistent organic pollutants (POPs), drafted by 122 nations in South Africa in December 2000, targeted PCBs as one of the dirty chemicals to be phased out globally. Some countries, in particular developed countries, banned the production of PCBs many years ago (e.g. the USA in 1976). However, due to the persistence of PCBs in the environment, they continue to be a food hazard, even in countries that banned their production a long time ago.

Dioxins are only slightly volatile, and therefore tend to show limited geographical distribution (e.g. a lake, or a portion of a river) mainly following fallout from the smoke plumes of combustion, and in water courses thereafter. By now, however, they can be found in many areas all around the world. PCBs have low water solubility (also they remain on the water surface). However, in contrast to dioxins, PCBs are highly volatile; the result is that PCB contamination can be found worldwide, including the Arctic and Antarctic regions. Both dioxins and PCBs are highly soluble in lipids and therefore tend to accumulate in animal and human lipids. Fat in milk, meat, eggs, fish and their products are the main source of dioxins and PCBs in our diet.

Dioxins and dioxin-like compounds may be accumulated in fish, either from the water with which they are in contact (freshwater or seawater) or from contaminated feeds. In practice it is impossible to avoid some contamination with dioxins and, in particular, PCBs; however, it should be possible to avoid specific geographical locations (land or water) that may be exposed to significant contamination by dioxins and PCBs. Accumulation of dioxins and PCBs by fish directly from water is possible, but this route is generally considered negligible for species at the top of the trophic chain.

Usually, high-energy feeds are the first cause of concern. Studies conducted in various countries have shown that cultured fish, particularly those reared on aquafeeds containing fishmeal and fish oil, exhibit levels of dioxins and dioxin-like substances greater than those found in wild fish (Easton, Luszniak and Von der Geest 2002; Hites *et al.* 2004). These findings could also be related to the amount of these substances in the fish feed used, particularly in the fishmeal and fish oil incorporated. Limits for dioxin and dioxin-like substances in fish and fish products exist in almost all countries (for example, in the case of the European Union, Council Regulation (EC) No. 2375/2001, 29 November 2001, applies). Despite the findings mentioned above, it is important to note that all studies to date have shown that the levels of dioxins and PCBs in both wild and farmed fish are generally well below regulatory and advisory limits; however, concerns about this type of hazard remain.

Regular surveillance, particularly in developed countries, shows that levels of dioxins and PCBs in the human diet and in body lipids (e.g. mothers' milk and blood) have generally fallen substantially since the mid-1980s, following the enforcement of improved regulations on garbage combustion, the ban on the production of PCBs, and the development of regulations regarding the disposal and handling of PCBs. Nevertheless, the risk of these types of hazards may be significant in specific geographical areas where such measures do not apply, or only partially apply, or due to the faulty implementation of regulations.

Other possible sources of chemical contamination may include fertilizers, pesticides, drug-residues, disinfectants, chemotherapeutants, medicines for disease control in fish, antifoulants used in cage nets, etc. The number of possible hazardous substances is very large; therefore specific hazard analysis may be necessary in each specific location. In any case most countries have regulations that define the specific obligation to establish an approved residue-monitoring plan for aquaculture that includes fish, water and sometimes feeds.

The potential exists for the strains of some human pathogens, such as *Streptococcus* (Weinstein 1997), to develop high antibiotic resistance, resulting in infections that can be more difficult to treat. Resistance can spread to other types of bacteria and human pathogens, through gene transfer mechanisms special to bacteria (Dixon 2000).

Preventing pre-harvest contamination is quite difficult, since most of the pathogens occur naturally but can be controlled by Best Management Practices. If operators are to remain competitive, they will have to follow the market pressure to achieve improved Food Safety Standards and bear the high economic cost of prevention procedures.

Risks of contamination in harvesting and processing

The way in which fish are harvested may also impact quality. It follows therefore that good techniques are very important to reduce the risks of contamination. The stress due to the transportation and handling of live fish during the rearing process and during partial harvesting can also cause an immunodeficiency, decreasing their resistance to infections by pathogens, bacteria, etc. Oxidative stress research is particularly important in the health assessment of farmed fish; stressed fish are more vulnerable to disease due to an impairment of their antioxidant defence systems (Ferrante *et al.* 2003).

During the harvesting and processing of the various fish products, pathogenic agents that are present in the raw fish may survive in the final product. Further contamination may also occur, due to biological (bacteria, scombrotoxins, parasites) and physical hazards. Human pathogens that may contaminate the fish product during post-harvest handling include *Bacillus cereus*, *Listeria monocytogenes*, *Staphylococcus aureus* and *Clostridium perfringens* (Feldhusen 2000). *Clostridium botulinum* is an ubiquitous, spore-forming, anaerobic organism that produces a neurotoxin causing life-threatening food-borne illness. *C. botulinum* type E is naturally found in aquatic environments and is often isolated from fish. The mere presence of *Clostridium botulinum* in or on a fish product will not cause illness, however; viable *C. botulinum* spores must also be given the opportunity to germinate and produce toxin. If the fish are properly handled and processed, to prevent growth of the organism and production of the toxin, there should be no risk of botulism. Although the hazard of *C. botulinum* toxin is serious, the risk is low because of the implementation of strict specific regulations (e.g. LACF – Low Acid Canned Food) in many countries. Another form of toxins are the scombrotoxins, which will be described in a later section because of their particular importance in capture-based aquaculture.

The allergy producing substance histamine will develop in fish where large amounts of free histidine and bacteria are present. Histidine may be converted to histamine if the products are stored at elevated temperatures for a sufficient time. The dynamics of histamine formation depend on a number of factors, for instance the type of fish flora, the ratio between external surface and weight, high temperature/shorter time and inappropriate handling of the fish. The higher temperature allows the bacteria that decarboxylate histidine to histamine to proliferate and produce substantial amounts of the active agent, the enzyme histidine decarboxylase (Chamberlain 2000). High histamine levels indicate that the fish have been stressed during the harvest operation and stored at high temperatures for a prolonged period, giving rise to toxicity. Sedation of the fish during harvesting, and effective temperature controls during handling and processing, are practical solutions to minimize this hazard. In the past, high histamine levels in seafood products exported from the Indo-Pacific region have resulted in severe economic losses and a number of importing countries have now introduced regulations on the maximum allowable histamine content (Chamberlain 2000). For example, the United States Food and Drug Administration has established an upper histamine limit in raw and frozen tuna of 50 ppm, and has also specified a health hazard (scombrotoxic) limit of 500 ppm (USFDA 1996). Histamine is considered a toxic or deleterious substance because, if ingested at sufficiently high levels, it is known to cause scombroid poisoning. The presence of other amine decomposition products in fish may also have a synergistic effect of histamine toxicity (Lehane and Olley 2000). Histamine fish poisoning (HFP) is a mild illness, but it is important in relation to food safety and international trade. HFP occurs throughout the world (Mines, Stahmer and Shepherd 1997); however, there are no reliable statistics on its incidence. Since 1970, the countries with the highest number of reported cases are Japan, the United States and the UK. Fish containing histamine may look fresh in terms of appearance and colour; therefore such quality attributes are not adequate to assess the presence or absence of histamine. HFP is a significant public health and safety concern; it was first diagnosed in 1828, and since then it has been described in many countries, being now the most prevalent form of seafood-borne infection in the United States.

Consumers are becoming more demanding, and litigation following food poisoning incidents is more common. Producers, distributors and restaurants are increasingly held liable for the quality of the products they handle and sell. Such forms of illness, which are a consequence of improper handling or storage of fish, need to be controlled by effective testing methods to identify those fish likely to be toxic. Control and prevention are possible (Lehane and Olley 2000), and many countries have set guidelines for maximum permitted levels of histamine in fish, following the USFDA. However, histamine concentrations in a spoiled fish are extremely variable, as is the threshold toxic dose. Biotoxins usually survive in cooked fish, while parasites are killed when fish is frozen or cooked.

The main problem associated with distribution of seafood products is time-temperature and inappropriate handling (Figure 148). Most bacteria cannot proliferate at temperatures below 5°C; thus the proper cooling of seafood during transportation becomes an important consideration. Chilled products should be loaded when the core body temperature is below 4°C for fresh products, and below -18°C for frozen products.

Few pathogens are generally present in smoked products but there is still a high incidence of *Listeria*. The risk posed by the consumption of cooked (fresh or frozen) fish is also low. The principal food safety risks associated with cooked products are caused by heat stable chemicals or biotoxins (ciguatera or fish containing an excess of histamines). An indirect hazard for human health is an allergic reaction to the ingestion of dead parasites; in general this risk is considered by authorities to be very low but current regulations exist, particularly in developed countries. Processed seafood sometimes also exhibit physical hazards, such as contamination with foreign material (glass, metal) (Huss, Reilly and Ben Embarek 2000). Maintaining healthy conditions during processing can be achieved through preventative measures, such as GMP, effective hygiene and sanitation programmes, etc.

Figure 148. One of the major problems in seafood distribution is inappropriate handling (Photo: M. Nakada)

Hazards of special relevance to capture-based aquaculture

A number of biological (bacteria, viruses, parasites, and biotoxins such as ciguatoxins and scombrotoxins), chemical (heavy metals, pesticides, antibiotics) and physical (foreign bodies) hazards may be associated with capture-based farmed seafood products. Some of these may derive from naturally present environmental contaminants in which the fish are captured or farmed; others may be due to contamination introduced during processing. Most of these problems have already been described in the previous section of this chapter; the following extra comments draw attention to problems of special relevance to capture-based aquaculture.

Pre-harvest contamination

All of the problems described earlier, in the section on general hazards in wild and farmed seafood, are also applicable to some capture-based aquaculture products; a number have special relevance to this part of the aquaculture sector. For example, in the capture-based aquaculture of eels, 21% of Japanese eel culture ponds were reported to be contaminated with *Salmonella* in 1989 (Huss, Reilly and Ben Embarek 2000).

In several types of capture-based aquaculture there is a need to develop a suitable practical diet for grow-out production. Trash fish is often used as a principle source of feed in these forms of aquaculture, and can be a source of infection and some diseases involving opportunistic parasites. For instance, the trematodes, cestodes, nematodes and acanthocephalans recovered from cultured groupers were thought most probably to be transmitted through the trash fish that was fed to them (Bondad-Reantaso, Kanchanakhan and Chinabut 2001). Parasitism is an ubiquitous phenomenon in the marine environment, and in capture-based aquaculture there is the potential to develop several parasitic infections, which may be zoonotic if the fish is eaten raw. In groupers (*Epinephelus suillus*), the source of infection may be the fresh trash fish used as feed in the capture-based aquaculture practices applied. In other cases, the correlation between parasitic nematode species and their relative infections and the use of fresh trash fish cannot be ascertained, because their pathogenicity in humans has not yet been established.

Other problems occur in capture-based aquaculture due to the common practice of "seed" importation. In Japan, for example, the capture-based aquaculture of amberjack is based on the importation of fry from Hainan, China and Hong Kong. This trade developed due to the lack of juveniles available in Japanese coastal areas (Ogawa 1996). The increase of fry imports was correlated with an increase of the monogenean infection (*Neobenedenia girellae*) that suddenly appeared in these fish. It seems that the fry were infected before shipment to Japan. Since this parasite is not host-specific, infection can spread to other domestic fishes (Ogawa 1996), including grouper (Bondad-Reantaso, Kanchanakhan and Chinabut 2001).

The fish families involved in ciguatera poisoning include several capture-based farmed species, including serranids (groupers) and carangids (yellowtails). An example of this type of seafood-borne infection occurred in Haiti in 1995, and was due to the consumption of cooked greater amberjack, *Seriola dumerili* (Poli *et al.* 1997). This infection is usually limited to wild fish. There is a potential to control such contaminations in capture-based aquaculture, so there could be a possibility of guaranteeing ciguatera-free fish (Sadovy 2000), thus providing a marketing opportunity.

Tunas are recognized as predators able to concentrate large amounts of heavy metals (Voegborlo *et al.* 1999), depending on their origin. This therefore represents a potential problem for capture-based aquaculture. Eels (*Anguilla* spp.) are good candidates for the investigation of mercury bio-accumulation, due to their long life spans in freshwater systems. Studies in Australia, Europe and New Zealand have shown mercury bio-accumulation in eel tissues (Redmayne *et al.* 2000). However, in general it is wild fish that accumulate high levels of heavy metals. Capture-based aquaculture, being based on the on-growing of wild "seed" in controlled systems where water quality and diets are controlled, should be less susceptible to this problem. In the wild, the larger and older the fish, the greater potential for the accumulation of heavy metals in its tissues exists.

The risk of dioxins and PCBs in fish reared through capture-based aquaculture should be low, and comparable to the levels found in wild fish, when they are fed raw fish (fresh or thawed). In any case, the levels of accumulation in the cultured fish will depend mainly on the levels of dioxins and PCBs in the feed presented, whether it be raw fish or a compounded aquafeed. For instance it is known that the levels of dioxins and PCBs in species of small pelagics fished from the South Pacific off South America are lower than those of similar species in the North and Baltic Seas.

Japan has banned the use of organic tin coatings, the application of a chemical substance to the nets used by the farmers of yellowtails to prevent the growth of fouling organisms, for fear of its accumulation in fish tissues and consequential human health concerns (Ogawa 1996). Initial investigations of human blood and livers have shown enhanced concentration of some organo-tin derivatives (Hoch 2001).

Permitted chemotherapeutants, such as the antimicrobials used in capture-based aquaculture to prevent infectious diseases in fish, may lead to the presence of residues in fish flesh and to the development of antibiotic resistance in both humans and fish-pathogens (Schnick 2001); this practice therefore needs control.

Risks of contamination in harvesting and processing

All of the problems described in the earlier section of this report, on the general hazards in wild and farmed seafood products apply to capture-based aquaculture. However, this section mentions some problems that are particularly important for this sector.

Thunnus spp. are known to be easily stressed (Figure 149); if the tuna are over-stressed, the muscle can become “burned”. This is due to the production of lactic acid by the anaerobic glycolysis process. Stress also can create high levels of histidine to be produced, which creates the HFP problems that have been described earlier. Scombrotoxins (biogenic amines) are biotoxins that are produced mainly in scombroid fish species, such as tunas, due to inappropriate handling during harvesting and poor post-mortem conditions, particularly when these fish are kept at elevated temperatures (>5°C). It is important to highlight this hazard, since high levels of histamine in bacterially contaminated fish of these particular species can be toxic to the consumer. It is thus of importance in capture-based aquaculture, particularly to tuna farming. It has been noted that cooked fish have been involved in a higher number of cases of HFP than raw fish in Japan. Given the Japanese preference for raw fish, this may seem surprising but it is probably due to the fact that only the highest quality fish are sold in the raw fish markets there.

Other species that are reared in capture-based aquaculture are also associated with HFP. These include amberjack (*Seriola* spp.) and yellowtail amberjack (*Seriola lalandi*). The fish used as feed in some forms of capture-based aquaculture can also be associated with HFP; these include herrings (*Clupea* spp.), anchovies (*Engraulis* spp.), and sardines (*Sardina pilchardus*).

Figure 149. Capture-based farmed tuna; the harvesting time is a delicate phase because tuna are easily stressed (Photo: L. Mittiga)

Strategies for food safety and quality

Hazard analysis and critical control point (HACCP)

By the end of the 1980s, developed countries arrived at the conclusion that classic food inspections, based on the analysis of samples of the final product and on generic hygiene measures, were not enough to provide the necessary level of protection to consumers. Inspection needed to address all the relevant hazards in food production and therefore had to be incorporated into the harvesting, processing and distribution of fish products. The system that was eventually developed was called "Hazard Analysis and Critical Control Point" (HACCP). In the HACCP system, each substance, micro-organism, pest, or condition which can contaminate the food is identified and called a "hazard". By the beginning of the 1990s, developed countries were already applying HACCP on a voluntary basis. In 1997, it was incorporated into the WHO/FAO *Codex Alimentarius* in the form of a general guideline; subsequently, the system was officially adopted, and governments started to change their regulations accordingly (FAO 2000).

The plethora of regulations, agreements and guidelines concerning the safety of aquaculture products around the world has become a rather complex matter, as there are many international and national texts. The relevant internationally agreed texts are the GATT Agreement on the Application of Sanitary and Phytosanitary Measures (GATT 1994) and the basic *Codex Alimentarius* Commission (CAC) texts on food (including fish) safety. There are also FAO and WHO texts of particular relevance to farmed fish, such as the FAO aquaculture guidelines (FAO 1997b) and the food safety issues discussed in a paper by FAO/NACA/WHO (1999). A specific section for aquaculture will be adopted in the Code of Practice for Fish and Fishery Products of the *Codex Alimentarius* (http://www.codexalimentarius.net).

At the national level, many countries have now adopted specific HACCP-based regulations regarding the safety of fish and fish products, including the products from aquaculture. Approximately 65% of the total international fish trade is now carried out under HACCP-based regulations. Regional regulations also exist. For example, there are a series of directives in the European Union that enforce the use of HACCP systems. Directive 91/493/EEC of July 1991 lays down the hygienic conditions for the production and placement of fishery products on the market; 93/43/EEC (14 June 1993) is also applicable to fishery products; and the Commission Decision 94/356/EEC (20 May 1994) sets detailed rules for the 1991 directive, with regard to hygiene checks on fishery products, to ensure that producers follow and adhere to the requirements of the EU.

Regulations are changing very quickly; further changes and new regulations are likely in the next few years. Moreover, the HACCP-based regulations of different countries are not fully equivalent from the point of view of the analysis of regulatory texts. Future regulations will tend to include either direct quantitative risk analysis of the relevant hazards associated with a given product, or some indirect measurement of those risks (Lupín 2000).

The application of the HACCP system to capture-based aquaculture

While the implementation of HACCP-based food safety assurance programmes is well advanced in the fish processing sector, their application to fish farming generally (including capture-based aquaculture) is still in an early phase. The lack of scientific data regarding the effectiveness of the on-farm control of pathogenic micro-organisms is one of the problems that cause the insufficient application of HACCP in capture-based aquaculture.

A prerequisite for implementing an HACCP system in any fish farming operation is compliance with the principles of good aquaculture practice, sometimes known as best management practices (BMP). Good aquaculture practices can be defined as those practices necessary to produce high-quality products conforming to food laws and regulations of the intended marketing country. Governments should strive to promote the use of such practices through the education of farmers and the promotion of food safety procedures.

The successful application of HACCP requires the full commitment of the owner of the fish farm, together with its workforce and expert team (Figure 150). It is necessary to examine carefully the nature and extent of any hazards associated with products from aquaculture, and their methods of production. The first step is to assemble an HACCP team that should include experts in all the activities related to fish farming. This multidisciplinary team should consist of experts in aquaculture, fish farm management, fisheries extension, public health, parasitology, and fish inspection and quality control. The second step involves a description of the product and its intended use by the purchaser. The intended use may include processing as value-added products or consumption after cooking. The third step involves designing a flow diagram. The fourth step involves the on-site confirmation of the flow diagram approach. Finally, the fifth step consists of the application of the seven principles of the HACCP system (FAO/NACA/WHO 1999), adapted to production from capture-based aquaculture.

Figure 150. Harvesting of Japanese amberjack in Japan; in future, capture-based aquaculture will apply the HACCP system (Photo: M. Nakada)

There is an excellent text available from EUROFISH, in conjunction with SIPPO (the Swiss Import Promotion Programme) called "Guide to Hygiene within the Fish Industry" (J. Dallimore, pers. comm. 2002) that details all of the requirements for HACCP accreditation, and is full of illustrations showing the requirements in action.

An effective HACCP system must control the production and delivery of products from the first day that the fish are held in captivity until they are delivered to the consumer. The documentation must allow full traceability. The systematic procedure for setting up an HACCP system is as follows:

- analyse the complete production process and estimate the probability of a hazard occurring, and the risks involved. In capture-based aquaculture there are six main areas of concern: collection, on-growing, harvesting, packing and processing, delivery, and point of sale;
- determine the Critical Control Points (CCPs) that may be present in the system. These may include the quality of the trash fish used as feed, harvesting operations, hygiene in the packing area, temperature control levels, etc.;
- specify the limits which, when adhered to, will guarantee that the CCPs are under control (e.g. fresh fish always to be kept below 5°C after harvest);
- establish protocols and documentation for monitoring the CCPs;
- develop and specify corrective actions when monitoring reveals that a CCP is no longer under control;
- establish procedures for modification that include supplementary tests and procedures to confirm that the HACCP system is working effectively;
- develop a complete documentation system that records all of the stages necessary to the system.

It must be noted that to establish and maintain an HACCP system is a complex and time consuming operation, but one that must not be ignored. It is suggested that all companies employ a consultant experienced in HACCP systems to evaluate the CCPs needed, and to provide training to management and staff to ensure that the criteria in the system are met.

Environmental certification and its application to capture-based aquaculture

Environmental certification of aquaculture is increasingly seen by many as a multipurpose instrument. It represents a means for aquaculturists to produce value-added farmed organisms and a means for environmentalists to increase the level of environmental awareness and protection in the industry. An environmentally certified product gives consumers assurance on quality and some sensitivity to the way that the product is produced. Consumers can then make informed purchases; this can constitute a method for minimizing the risk faced by retailers of being accused or found guilty of supplying products that are produced in an environmentally unsustainable way (Mallows 1999). Such considerations should be also applied to the products of capture-based aquaculture.

Currently, the driving force behind eco-label initiatives derives mainly from Agenda 21 of the UN Conference on Environment and Development held in Rio de Janeiro, Brazil in 1992 (www.un.org/esa/sustdev/agenda21.htm), which were reinforced by the fisheries agreements that were achieved during the 2002 Summit in Johannesburg (www.johannesburgsummit.org). Many NGOs have taken up this topic; some of their views are extreme; others are more balanced. For example, a report on aquaculture for a US-based NGO, the Environmental Defense Fund (EDF) presents recommendations for the private sector of aquaculture, such as "Organic certification and potentially other eco-certification programmes should be established that empower consumers to choose aquaculture products grown in an environmentally sound manner..." (www.edf.org).

The labelling of a product as "environmentally certified" is based on an assessment of its entire cycle, extrapolated both upstream and downstream, and is dependent on a systems approach, e.g. Environmental Management System (EMS) to production, distribution and marketing. There are two main standard systems specifications for implementing an EMS: the ISO (International

Organization for Standardization) 14000 series and the EU-accredited Eco-Management and Audit Scheme (EMAS). Neither is legally binding. The ISO series is still being developed, and its components include standards for Environmental Auditing (ISO 14010-14013), Environmental Site Assessments (ISO 14015), and Eco-labelling and Self-declaration Environmental Claims (ISO 14020-14024). The main certification criteria involve the development of an EMS. The required components for ISO certification are included in ISO 14001. For initial design, development and implementation, an EMS ISO 14004 can be used, as it consists of a set of guidelines rather than a full auditable certification criterion (Mallows 1999).

Eco-labelling is currently gaining acceptance in USA and EU markets. The Marine Stewardship Council (MSC), an organization supported by commercial interests that promotes the sustainable exploitation of the sea, has considered extending its eco-labelling system for capture fisheries to aquaculture (M. New, pers. comm. 2003). A certification system designed specifically for aquaculture has been developed by the Aquaculture Certification Council (ACC), but is currently confined to marine shrimp and prawns (ACC 2003); this initiative has its origins in a producers organization, the Global Aquaculture Alliance (GAA) and may therefore be subject to scepticism about its independence.

Recently, ecolabelling has become a major issue in the USA where the public is informed in restaurants and information points (such as university aquariums) under the Seafood Watch Program. Products are graded as “best choices”, “proceed with caution” and “avoid”, and in restaurants the consumer is also advised if a fish product is “environmentally sustainable”. Capture-based aquaculture will need to address these issues where products are sold in these sensitive main markets (www.intrafish.com/articlea.php?articleID=25219).

In response to growing public concerns about food quality, two of Japan’s biggest supermarkets, Aeon Co. (formerly Jusco) and Ito-Yokado Co., plan to improve the information provided on fish labels. The labels will include information on the origin of the fish, including “production histories” covering data on the farming area, the farming company and the feedstuffs used. Aeon Co. began this programme by labelling eel products in May 2002. By 2003, it planned to include other farmed fish such as yellowtails. It will also provide details of its own management of the fish farming process, and display information on whether its fish have been given anti-infective drugs (www.asahi.com/english/business/K2002032700610.html).

In 1995 the Food and Agriculture Organization of the United Nations (FAO) adopted a Code of Conduct for Responsible Fisheries (FAO 1995). The CCRF sets out principles and international standards of behaviour for responsible practices, with a view to ensuring the effective conservation, management and development of living aquatic resources, with due respect for ecosystem and biodiversity. The Code recognises the nutritional, economic, social, environmental and cultural importance of fisheries (including aquaculture practices), and the interests of all those concerned with the fisheries sector. The CCRF takes into account the biological characteristics of the resources and their environment, and the interests of consumers and other users. The Code is not legally binding, but FAO Member States and all those involved in fisheries are encouraged by FAO to apply it.

The feasibility of implementing a certification scheme in an aquaculture operation can be compared to other similar situations. Quality assurance, together with safety assurance such as HACCP, can be integrated quite simply with certification criteria; it is easier to incorporate existing quality and safety schemes into something new, such as a certification system, than to try to add a certification process to an existing assurance scheme. The inclusion of documentation on traceability is also essential for insurance purposes. The problem that must be addressed is performance monitoring (use of resources, waste discharge, etc.). By using a separate organization to verify certain aspects of aquaculture production, the farm and the certifiers must both ascertain whether performance targets are being achieved and maintained. The operator, the regulating body or the certification organization can undertake this monitoring activity, though it would be better if all parties shared the responsibility.

Conclusions

The expanding trade in capture-based farmed species of various ages and life stages for the seafood industry without appropriate health considerations may increase the risk of spreading pathogens that are associated with human illnesses. Little is known about the impact of contaminated food on human health and its epidemiology. Food safety concerns associated with capture-based aquaculture affect all levels of this activity. Illness caused by the consumption of contaminated food not only has socio-economic consequences (e.g. production losses) but also causes public health concerns. Such problems may seriously affect small-scale farmers, who represent the backbone of many rural communities in Asian aquaculture. Their livelihoods may be threatened through reduction in food availability and loss of income and employment.

The level of hygiene during the production and consumption of seafood in Europe keeps bacterial risks at a low level (Feldhusen 2000). Food-borne sicknesses associated with capture-based farmed products could be largely prevented and controlled through appropriate food-safety measures. Responsibility for food safety associated with the products from aquaculture is shared between governments, fish farmers, the processing industries, and consumers.

Reducing the number of seafood-related sickness outbreaks worldwide requires continued and coordinated efforts by many different agencies, including those involved with water quality, disease surveillance, consumer education, and seafood harvesting, processing, and marketing (Feldhusen 2000). Where appropriate, the aquaculture sector should institute farm management programmes based on the principles of the HACCP system, which should be applied at all stages from production, collection and transport, to the consumption of food. This would allow a systematic approach to the identification and assessment of the hazards and risks associated with the production, distribution and use of aquatic food. The application of HACCP-based food safety assurance programmes in fish farming is in its early phases (FAO/NACA/WHO 1999). Strategies for food safety guarantees and education must be enhanced among communities where eating raw or inadequately cooked fish is a cultural habit.

Capture-based aquaculture provides opportunities to reduce the risks associated with food safety. For example, in the culture of species where ciguatera is problematic, capture-based farmed species could be “certified” ciguatera-free, so that they would be regarded as a safe source of fish for human consumption (Cesar *et al.* 2000); this could assist profitable marketing.

The development of certification systems that assure quality and good practices should be advantageous for capture-based aquaculture operations, providing such schemes are manifestly independent and accepted as valid by consumers. Research is also necessary to reduce the risks associated with the feed consumed by capture-based farmed species.

chapter 11

GENERAL CONCLUSIONS AND FUTURE PROSPECTS

11

GENERAL CONCLUSIONS AND FUTURE PROSPECTS

Capture-based aquaculture can be considered the mid-way point between fishing and aquaculture, yet as a commercial activity it constitutes a distinct sector. Its success provides the potential to stimulate research into developing new species for aquaculture, and it has the benefit of existing markets ready for aquaculture production.

It is clear that a very significant proportion (many millions of metric tons) of the total foodfish (finfish, crustaceans and molluscs) aquaculture production reported by FAO is obtained through the on-growing of wild-caught juveniles (for example, in addition to the four species groups considered in this report, the farmed output of milkfish (*Chanos chanos*), mullets, most molluscs, and some marine shrimp is derived from juveniles captured from the wild). However, it is impossible to quantify the total volume or value of the output from capture-based aquaculture accurately because, as yet, the data collected by FAO from its Member States does not distinguish between production from hatchery-reared and wild-caught juveniles.

Most of the production arising from capture-based aquaculture consists of molluscs. Considering finfish alone, the capture-based production of the species groups considered in this report (eels, tunas, groupers and yellowtails) represent a large proportion of the total volume and an even larger proportion by value.

The statistical returns to FAO (FAO 2002a) appear to underestimate production by about 15% for the four species groups covered in this report, when compared with the estimates and reports from other sources (Table 82).

Table 82. Data for the capture-based aquaculture production of eels, groupers, tunas and yellowtails in 2000

Species groups	Estimated data (tonnes)	References for estimated data
Eels	287 815*	Frost *et al.* (2000) www.glasseel.com
Groupers	15 000	Sadovy (2000) Kongkeo and Phillips (2002)
Tunas	20 000	Ikeda (2003)
Yellowtails	136 200	M. Mahita (pers. comm. 2002) and data from the Statistics and Information Department, Ministry of Agriculture, Forestry and Fisheries, Japan
Total	**459 015**	

* This is comprized of the sum of FAO data (FAO 2002a) and 50 000 tonnes of European eels (Frost *et al.* 2000) that are not specifically recorded in FAO statistics, together with the reported total production of 5 000 tonnes of *Anguilla japonica* in China and *Anguilla rostrata* in Asia (www.glasseel.com).

As indicated above, capture-based aquaculture contributes a significant proportion of total foodfish production through aquaculture, in terms of value as well as volume. For example, even considering the lower production figures reported to FAO, the total value of the capture based aquaculture of the four groups covered in this report exceeded US$ 1.7 billion in 2000 (FAO 2002a). It qualifies to be considered as a separate and distinct entity within the aquaculture sector, not only for its production volume and value, and its market relevance, but also because it has its own specific culture characteristics, which include the facts that:

- in developing countries, capture-based aquaculture constitutes an alternative livelihood for local coastal communities and can contribute significant positive economic returns in those regions with depressed marginal economies. In these countries, capture-based aquaculture is based on international joint ventures, driven by strong market demands and high values. It has a strong economic base, and production can represent eight times the value of the specific regional fisheries;
- capture-based aquaculture has the potential for significant economic multiplier effects, due to the labour intensiveness that is associated with operational and infrastructure requirements. Capture-based aquaculture needs new professionals, thus increasing employment opportunities. In some cases, it has brought about social stability (e.g. Port Lincoln, Australia) with better working conditions and regular incomes. In developing countries it can contribute to poverty reduction and the overall welfare of low-income, resource/asset-poor households;
- new market segments have been created by capture-based aquaculture. In Japan, for example, farmed tuna has filled the gap between two extreme food categories (high quality/expensive and low quality/cheap) and, with its affordable price and high quality, has become very popular. Another example is that farmed groupers are cheaper than comparable wild fish, and they are more competitive in the lucrative live fish market;
- capture-based aquaculture possesses some advantages that can reduce the risks associated with food safety. For example, capture-based farmed species can be "certified" ciguatera-free where control systems are established, so that they can be a safer source of fish for human consumption than wild fish. Consumers are becoming very sensitive to the health hazards associated with capture-based farmed species, as many of these products are normally consumed raw (e.g. "*sushi*", "*sashimi*"). With the application of HACCP, or other food safety assurance programmes, it will become possible for producers to increase their competitiveness in the market by guaranteeing high quality products. In Japan, capture-based farmed yellowtails have a good market image. The same can now be said for eels (through eco-labelling). Both examples are in response to the growing public concerns about food quality. For those capture-based farmed species that at present only enjoy a regional trade, quality will play a key role in the strategies needed to expand the market internationally.

However, what is still lacking is a thorough assessment of the sustainability of capture-based aquaculture, given its high complexity and reliance on "seed" material from wild stocks. By focusing on the selected species in this report, it has been possible to extrapolate a general overview of the capture-based aquaculture industry. This activity is influenced by several key factors and careful management is needed, together with further scientific research and other investigations, to ensure its future viability. These factors are highlighted below.

Wild seed supply

The supply of wild "seed" to the capture-based aquaculture industry appears to be unsustainable in the short term and inadequate in the long term. There are several reasons for this:

- the availability of the "seed" resource, determined bycatch per unit effort of "seed" (juveniles and/or adults), appears to be in decline;
- nursery and adult habitats (e.g. mangrove, sea-grass, coral) are increasingly damaged by pollution, destructive fishing practices and other environmental impacts;
- the actual status of stock resources (lack in knowledge of biology, age maturity, recruitment, etc.) remains substantially unknown;
- there is a lack of quality data on catches, biomass, sizes, etc., which is needed to manage the stock successfully;
- overfishing of the target resources occurs during normal fishing activities.

Solutions for these problems must include improvements in the management of each species, further studies on their biology, and specific research on more selective fishing gears. Moreover, there is a need to develop specific policies and legal frameworks for capture-based aquaculture that incorporate and create interactions between the fishing and farming sectors.

Seed transfer

The transfer of the "seed" to the farms creates additional problems, including:

- high mortality rates (through disease, cannibalism, transport stress, etc.);
- high cost (collection areas and farms are often far apart);
- inadequate holding procedures;
- conflicts with other resource users.

New technologies for the transhipment of wild fish to the farms are needed in order to reduce mortalities, while capture-based aquaculture activities must be properly regulated so that they do not adversely affect associated fisheries, or compete with other human activities.

Farm management

The culture (on-growing) systems also have a series of difficulties to overcome which include:

- the use of trash fish causes problems including the fact that the availability of bait fish is unpredictable (seasonally, etc.), and there is an inappropriate assessment of the related environmental impacts, such as bait fish stock depletion, diseases and infections, etc. The use of raw trash fish may not only cause the transfer of disease vectors to the farmed fish but to other fish sharing the same water body. The transfer of human pathogens is also possible;

- the use of inadequate technologies (feeding regimes, lack of specialized formulated feeds, poor mooring systems and cage structures, etc);
- the currently limited research that would establish optimum conditions for on-growing facilities, which in turn would result in the development of better equipment for offshore operations;
- the lack of trained personnel, with many operations being undertaken at an artisanal level, resulting in poor performance and loss of fish.

An important breakthrough will come when specific cost-effective formulated diets are developed for each species, and accepted by the farmers. The substitution of trash fish by compound feeds will lower the dependence on capture fisheries, thus indirectly protecting marine resources. It will also reduce the pollution caused by waste feed, promote a favourable ecological equilibrium, enable diet quality to be controlled, guarantee a more efficient feed conversion ratio (thus reducing handling and feeding costs, although the ultimate economic gain through such improvements depends on the relative unit costs of the alternative feeds, as well as FCR; other factors also need to be taken into account, such as the final consumer acceptability, and therefore value, of the products produced through alternative feeds. These factors are important considerations, because they heavily influence the willingness of farmers to change from current feeding practices), and eliminate the health risks associated with the uncontrolled quality of bait fish.

With the development of equipment suitable for offshore cage locations, better water quality and fish health will result. Such developments will require consequential improvements in feeding systems, larger boats for servicing them, and new techniques for net repair and cleaning and the maintenance of mooring systems. Increased automation, electronic monitoring, and the use of tension leg mooring systems are possible solutions.

Environmental and safety issues

Environmental and safety issues are always high on the list of concerns for aquaculture generally, and particularly for capture-based farming; these include:

- the lack of an adequate, cost-effective environmental assessment system to ensure good site selection. The use of trash fish can create serious problems for water quality. Sites need to have good water circulation; be deep enough for the nets to be used, to minimize sediment build-up; and have good flushing characteristics to prevent eutrophication, etc.;
- existing regulations do not enforce regular environmental monitoring of site conditions, allowing the development of potentially harmful situations from farm pollutants, which may cause the operation to fail;
- the use of trash fish as feed will continue to have considerable environmental impacts; including wastes, oil skims, etc. The development of low-pollution diets for the various species would considerably reduce environmental impacts;
- the choice of aquafeed ingredient sources, and rearing or fattening sites, should include an assessment of the possibility of chemical contamination (e.g. by dioxins and PCBs) to ensure that farmed fish remain safe for consumption.

The negative effects of farm generated pollution represent a cost to the coastal environment and other resources users. Controlling and reducing wastes would be beneficial to the capture-based aquaculture industry. Sustainable practices not only preserve the environment and reduce the potential for conflicts with other coastal users, but also result in products that are perceived by the consumer as safe, thus improving marketability. An integrated and multidisciplinary approach is needed to develop and achieve sustainability. The development of rapid and innovative low-cost environmental impact assessment programmes, together with regular monitoring based on key environmental performance indicators, will be highly beneficial for the capture-based aquaculture industry.

Post-production issues

Harvesting, processing and marketing also need improvement. Existing problems include

- inappropriate or poor harvesting techniques;
- inappropriate or limited food-safety measures to guarantee consumer health;
- lack of knowledge of the effects of contaminated food on human health and its epidemiology (socio-economic and public health consequences);
- the absence of product traceability;
- limited commercial trade and restricted markets due to product type;
- limited product ranges, which leave producers exposed to market volatility;
- high transportation costs for the fresh "live" fish to market.

Strict (but enabling, not restrictive) procedures are needed to grant farming and selling licences, and for establishing inspection systems to ensure hygiene and quality. Such regulations would protect consumers and help producers to increase the competitiveness of their products in the market. There is a need to develop new market strategies and new market segments, because relying on a unique market (such as Japan for bluefin tuna) is becoming risky for capture-based aquaculture operators.

Control over the life cycle

Capture-based aquaculture needs to progress towards the control of reproduction and the ability to breed in captivity, as well as rear the various life stages of the farmed species. Until this final stage is reached (when formerly capture-based products become normal aquaculture products similar to farmed salmon or trout), the application of responsible techniques for capture-based aquaculture must be the rule. Generally, capture-based aquaculture represents the first (but sometimes, as in eel production, very lengthy) step towards true aquaculture. Thus it is essential that governments should explore and develop legal and institutional instruments to:

- recognize capture-based aquaculture as a distinct sector;
- integrate capture-based aquaculture concerns into resource use and development planning;
- set up international agreements, signed by all those countries that share the same resources, for specific actions in the sector;

- improve food quality;
- improve the management of capture-based aquaculture, particularly where the practice is unsustainable;
- actively promote the activity, as it is likely that it will lead to the development of new aquaculture species, thus reducing the pressure on existing wild stocks.

Statistical issues

For more than a decade FAO has been refining the questionnaires that it sends to Member States, to assist them in defining what production activities result in aquaculture output, from a statistical point of view, and what are regarded as capture fisheries production. Since the growth of the tuna fattening industry, some statistical difficulties have been experienced because of the size of the animals caught from the wild for stocking purposes. In 2001, the Coordinating Working Party on Fishery Statistics (CWP) addressed this issue (Fishstat Plus 2002) and decided that in tuna fattening practices the weight of the captured tuna should be recorded as capture fishery production and that subsequent incremental growth in captivity should be recorded as aquaculture production, in order to avoid partial or total double counting. However, while this solution is theoretically correct, there are practical difficulties in weighing the fish twice. This matter therefore is still under discussion and remains to be satisfactorily resolved; until it is, some difficulties in interpreting the statistical data relating to those species of tuna that are fattened in farms exist. Cooperation between FAO and the tuna fattening industry to develop appropriate rates for measuring increments over time, so that the correct proportions of total production can be assigned to the statistical returns for capture fisheries and aquaculture production, is essential. While this matter is a serious problem relating to tuna fattening, there are no similar statistical problems with the other species discussed in this report (eels, groupers, yellowtails) because the animals caught from the wild for stocking into aquaculture rearing units are negligible in weight; in these cases, the total production is recorded as aquaculture. However, similar statistical problems to those experienced with tuna fattening may occur in reporting the output from the on-growing of other species that are stocked from the wild (e.g. cod).

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. In the case of non-finfish species, such as a variety of bivalves (e.g. mussels), the activity will certainly continue in view of the very large number of gametes released.

However, in the long term, the capture-based aquaculture of selected 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.

Researchers worldwide have been working for many years on the reproductive cycles of all of the species dealt with in this report, achieving results that range from a hint of success in the case of eels to partially successful ones in the case of bluefin tunas and selected species of groupers.

The reproductive biology of the species covered in this report varies in complexity. So far, however, in no cases has their “seed material” been produced artificially on a commercial level.

Research activities focused on fully controlling the reproductive cycles of these fish species will therefore continue as long as there is a high consumer demand for them. The importance of these efforts will be emphasized if their capture fisheries are threatened as a result of current exploitation and farming practices. The impact on eel fisheries caused by farming activities is already evident. It is possible that the capture and export of elvers for this purpose may become totally banned; in this case the farming of eels will cease unless economical means of rearing them artificially to the stocking size are by that time available.

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 the case of tuna fattening, future expansion will be constrained by limited fishery quotas. Eel farming is already constrained by the shortage of “seed” and future expansion is likely to be limited by controls over elver capture. Damage to the environment (e.g. by the collection of grouper seed) may also result in controls that will limit expansion. There is enhanced interest in yellowtail farming but, again, the limitation is “seed” suply.

Although the volume of market demand affects the rate of expansion in the farming of the species discussed in this report, the ability to supply that market will depend primarily on the supply of “seed” and on keeping farming costs down. 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 12

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Abbreviations and acronyms

ACIAR	Australian Center For International Agricultural Research
APEC	Asia-Pacific Economic Cooperation
APGN	Asia-Pacific Grouper Network
ASETUN	Spanish bluefin tuna Farmers Association
BOD	Biochemical Oxygen Demand
BTSD	Blue Fin Tuna Statistical Document
CAC	Codex Alimentarius Commission
CBA	Capture-Based Aquaculture
CCP	Critical Control Point
CCRF	Code of Conduct for Responsible Fisheries
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CITES	Convention on International Trade in Endangered Species
CPUE	Catch Per Unit Effort
CZM	Coastal Zone Management
DVS	Departmental Veterinary Services
EA	Environmental Assessment
EDF	Environment Defense Fund
EEZ	Economic Exclusive Zone
EFP	Experimental Fishing Programme
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement/Study
EIFAC	European Inland Fisheries Advisory Committee
EMAS	Eco-Management and Audit Scheme
EMS	Environmental Management System
FAD	Fish Aggregating Device
FAO	Food and Agriculture Organization of the United Nations
FCR	Food Conversion Ratio
FFA	South Pacific Forum Fisheries Agency
GATT	General Agreement on Tariffs and Trade
GFCM	General Fisheries Commission for the Mediterranean
GHP	Good Hygienic Practice
GMP	Good Manufacturing Practice
HACCP	Hazard Analysis Critical Control Point
HDPE	High Density Polyethylene
HFP	Histamine Fish Poisoning
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of the Sea
ICLARM	International Center for Living Aquatic Resources Management (WorldFish Center)

ICM	Integrated Coastal Management
IHNV	Infectious Haematopoietic Necrosis Virus
IOTC	Indian Ocean Tuna Commission
IPNV	Infectious Pancreatic Necrosis Virus
ISO	International Organization for Standardization
ITQ	Individual Transferable Quota
IUCN	International Union for the Conservation of Nature
LIFDC	Low-Income Food-Deficit Country
LRFFT	Live Reef Food Fish Trade
LRFT	Live Reef Fish Trade
MMPA	Marine Mammal Protection Act
MSC	Marine Stewardship Council
MSY	Maximum Sustainable Yield
NACA	Network of Aquaculture Centres in Asia-Pacific
NMFS	National Marine Fisheries Service
NGO	Non-Governmental Organization
QA	Quality Assurance
RSIV	Red Seabream IridoViral
SARDI	South Australia Research and Development Institute
SCRS	Standing Committee on Research and Statistics
SDP	Southern bluefin statistical Document Programme
SEAFDEC	South-East Asian Fisheries Development Center
SIPPO	Swiss Import Promotion Programme
SPC	South Pacific Commission
SRAC	Southern Regional Aquaculture Center
TAC	Total Allowable Catch
TBOASA	Tuna Boat Owners Association of South Australia
TNC	The Nature Conservancy
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNESCO/CSI	UNESCO Environment and Development in Coastal Regions and Small Islands Unit
UNDP	United Nations Development Programme
USFDA	United States Food and Drug Administration
VPA	Virtual Population Analysis
VSN	Viral Splenic Necrosis
WHO	World Health Organization
WIOTO	West Indian Ocean Tuna Organization
WTO	World Trade Organization
WWF	WorldWide Fund for Nature
YAV	Yellowtail Ascite Virus

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.