# Transition in the Contribution of Living Aquatic Resources to Sustainable Food Security

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## INTRODUCTION

The old proverb

> *Give a man a fish and you feed him for a day, teach him how to fish and you feed him for a lifetime*

no longer holds. As human populations increase and natural fisheries resources diminish, knowing how to fish is not enough for today's fishers and their families; many would be better off learning how to grow fish or trying another trade altogether.

Global changes in living aquatic resources could threaten progress towards sustainable food security[1] in many parts of the developing world, but they could also stimulate improved use of living aquatic resources. Some of the outcomes depend upon actions taken today. Human impacts have already transformed the Earth's terrestrial environment and may well have changed the global atmosphere. Now we have evidence that the inexorable collision of natural resource limits, demography, technology and social values has triggered a global change in aquatic ecosystems and their living resources. Users in fisheries, aquaculture and related enterprises face a period of formidable transition as they have to adjust to the changes and an uncertain future outlook. The transition period in a complex system, however, is the time when actions, even small ones, can have the greatest impact.

This paper addresses the outlook for living aquatic resources in food security and how research can contribute to improving that outlook where it

[1] Food security is defined as "physical and economic access, by all people at all times, to the basic food they need" (AGROVOC, FAO's thesaurus used for AGRIS). Food security therefore embodies stable, sustainable and predictable food supply, equity through access for all (either though access to the means of production and/or purchasing power) and quality including nutritional adequacy for life functions. Speth (1993) noted that sustainable food security "fuses the goals of household food security and sustainable agriculture", therefore embodying the aspects listed and "the protection and regeneration of the resource base for food production—terrestrial, aquatic and climatic".

matters most—for the low-income people in the developing world. Aquatic products are frequently overlooked in food security discussions at the national and global level since they are rarely used in supply calculations (James 1994). Of four major studies reviewed by McCalla (1994), one by Brown and Kane (1994) was the only study to include fish and terrestrial animal products. Cereals dominate most calculations of per capita supply and food security.

In order to examine the role of research, we must first discuss the global situation and the outlook, since research directions must address the strategic issues of the transition and thus help contribute to its course. To date, research has played an important though narrow role in the management of living aquatic resources. The reasons for this are reviewed and an expanded and more effective role for research is described.

The changing status of aquatic resources became fully apparent in the early 1990s and has many causes. Affected are the resources, the people who use and consume them, production practices, management institutions, the environment which supports them, and the local, national and international legal instruments governing their ownership and use (Table 1).

The present transition follows the rapid expansion of harvesting from the oceans and an upsurge in aquaculture; greater areas and more resources are exploited for their animal and plant products. On the land, similar earlier expansions of hunting and gathering, and the later transition to cultivation and domestication, occurred when human populations were small, interactions between different human impacts were negligible, technology had much less power to transform practices and the environment, for better or for worse, and humans had little knowledge of the long-term environmental effects.

Now the transition facing aquatic resources is happening rapidly, and the impacts will be far reaching. Without urgent anticipatory action, the world could forego billions of dollars of income, lose tens of millions of tonnes of high quality protein food, sacrifice millions of livelihoods, experience severe natural resource and environmental losses, and fail to pick up potential benefits. The low-income people of the developing world will be the hardest hit when their fragile purchasing power and often tenuous access to the means of production are further challenged.

Any benefits arising from the transition may not be immediate and almost certainly will not be evenly distributed. In many cases, we do not have sufficient know-how to extract the benefits immediately; in others, interventions must be made urgently to reap the rewards. The cost of rehabilitation is escalating exponentially; in some cases the damage may become irreversible.

Total aquatic products supply is in decline. Most natural fisheries resources are exploited at or beyond their safe limits. Catch is declining as more stocks become exhausted and fisheries irreversibly lower biodiversity and change the genetic structure of aquatic populations. Aquaculture production is increasing and will expand further, but not initially as fast as natural resource

**Table 1.** Transition in world fisheries and aquaculture

| *Resources* | *<1990s* | *>1990s* |
|---|---|---|
| Fisheries | At limits | Beyond limits<br>More stocks collapsed |
| Aquaculture | Expansion | Expansion continues |
| Uses | Food, feed | Increasing non-food use |
| *Society, Economics* | | |
| Number fishers | Increasing | Decreasing |
| Number fish farmers | Increasing | Increasing |
| Resource conflicts | Starting, few solutions | Increasing, more solutions |
| Economics | Overcapitalization | Structural adjustments forced |
| Trade, price | Increasing | Increasing |
| *Production Practices* | | |
| Fisheries | Restrictions | More restrictions |
| Aquaculture | Technology application begins | Increasing technology |
| *Environment and Climate* | | |
| Impact on/of fisheries, aquaculture | Increasing | Increasing to severe<br>Aquaculture assists sustainability |
| *International Arrangements* | | |
| | UNCLOS | + Agenda 21<br>Straddling stocks<br>Responsible Fishing<br>ICBD |

production declines. Fish prices are rising and trade is increasing, especially from the developing to the developed world.

As populations increase, per capita fish consumption is now declining, after almost doubling over the last three decades. Meantime, coastal populations burgeon, putting pressure on all coastal resources, and land-based resources are becoming more degraded and scarce. Inland, however, many more small farmers could add aquaculture in small ponds or rice flood waters to their enterprises and, through diversification and more integrated resource use, win greater income and food sustainability.

Pollution, mainly from the land, and habitat destruction in marine and inland aquatic environments are starting to further degrade the resource base.

This trend will continue for the immediate future throughout the developing world, thus reducing the carrying capacity of the environment. Natural and anthropogenic climate change will impel changes in the composition of ecological communities, in addition to those caused by fishing. Public concern over the environment and the impact of fishing practices on it will further restrict fishing practices but more in the developed than developing world.

National sovereignty over living aquatic resources will be strengthened, through powers granted under several international agreements, conventions and other legal instruments. But nations will need time and enhanced capacities to meet the objectives of the instruments.

Against this background, research agencies must target their efforts to addressing the issues of the transition in living aquatic resource status and use.

## TRANSITION

### The present situation in world fisheries and aquaculture

Aquatic resources are important food and economic resources for many countries (19% of total animal protein consumption or 4% of total protein, and valued at US$70,000 million in 1991 (FAO 1992a). As a food commodity group, fish products far outweigh any one of the four terrestrial animal commodity groups (beef and veal, sheep meat, pig meat and poultry meat). In the developing world fish production of approximately 60 million t approaches the total of all four animal commodities (approximately 70 million t). The International Center for Living Aquatic Resources Management (ICLARM) estimated that about 50 million people are involved in small-scale fisheries through catching, processing and marketing (ICLARM 1992). About 1 billion people rely on fish as their primary source of animal protein. Aquatic resources also provide important, though little recognized, environmental and cultural values and services now and for future generations.

Throughout 1994, the media and many multilateral agencies have highlighted a crisis in the state of world's fisheries, made public by earlier FAO and World Bank concerns (FAO 1992b, c; Garcia and Newton 1994; *Agriculture Technology Notes* 1994; Weber 1994a, b; World Resources Institute 1994), growing attention from major conservation groups, specific cases of collapsing fisheries in the developed world (e.g., the cod fisheries of the Grand Banks) and international fights over stocks between the fishers of various countries.

Five international initiatives, four coordinated through different arms of the United Nations system, will influence the transition in fisheries and aquaculture. The first initiative is to expand on the provisions of the 1982 UN Convention on the Law of the Sea (UNCLOS) to cover the management of high seas fisheries and straddling stocks. This initiative should be finalized in

1995. In the second initiative, FAO is coordinating the draft of a series of Codes of Practice on responsible fishing and aquaculture, encompassing the principles of the May 1992 Declaration of Cancun and the 1992 UNCED Agenda 21 (FAO 1993a). The third initiative is the global 1993 International Convention on Biological Diversity (ICBD). Its development was led by national conservation policymakers and coordinated by the United Nations Environment Program (UNEP).

The International Convention on Biological Diversity has had little impact yet on fisheries and aquaculture management and conservation, but is showing its potential to become the most influential instrument yet on fisheries, aquaculture and indeed agriculture, forestry and all human uses of life forms[2].

A fourth international arrangement, the General Agreement on Tariffs and Trade and the associated establishment of the World Trade Organization to implement the decisions of the Uruguay round of trade negotiations will also have an impact, through replacement of quotas by tariffs reducing over time, opening up some previously protected markets, and perhaps through environmental provisions. Environmental and natural resource issues, however, were downplayed in favour of rules against undesirable trade protection (*Economist* 1994).

The fifth initiative is the UN Conference on Population and Development being held in Cairo in September 1994 by the UN Population Fund. Its outcomes should have general implications for achieving an eventual balance between resources, development and population, but this does not obviate the impact of per capita consumption of resources—the other part of the equation when balancing people and resources. Reduced human populations will not eventuate in time to relieve the immediate pressures on aquatic products.

Another initiative which has stimulated activities in fisheries research and information is the follow-up action to the multi-donor Study/Strategy in International Fisheries Research (World Bank et al. 1993; *Naga* 1994).

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[2] The Convention on Biological Diversity defines biological diversity in a conventional scientific way as "the variability among living organisms from all sources including... terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part: this includes diversity within species, between species and of ecosystems". The Convention describes biodiversity as an attribute of life, distinguished from biological resources which "includes genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity". However, the Convention then points out that to fulfill legal obligations, parties will have to in fact conserve and manage biological resources and ecosystems. Therefore, the Convention contains the legal powers to govern all uses of life, including agriculture, fisheries, aquaculture and forestry. Agriculture has been touched early by the Convention because of its long and well-documented use and transformation of plant and animal genetic materials. Fisheries and aquaculture uses and impacts on biodiversity are less well known yet and thus aquatic biodiversity issues generally have received little attention.

**Production**

Capture fisheries production has reached its upper limits and is declining (Fig. 1). The expansionary phase of the 60s, 70s and 80s is over. For decades if not centuries, humans speculated and attempted to forecast the power of the oceans to feed the world (e.g., Gulland 1970; Idyll 1978). We have discovered these limits for the majority of natural fisheries resources[3], through a combination of scientific research and monitoring and some practical if unintended experiments of fishing stocks to or beyond their limits. The predictions of Gulland (1970) and FAO appear to have been right in aggregate (about 100 million t), though sometimes wrong in the detail[4]. Now the upper biological limit is falling for many species as overexploitation erodes the resource base. For most fisheries, in addition, the economic returns on operational costs and investments are negative, indicating that the economic values are totally depleted.

In 1992 preliminary estimates, world production was 81.5 million t of marine products (93% from capture fisheries) and 15.4 million t of inland aquatic products (45% from capture fisheries). Thus, the global dependence on production from natural fisheries resources was about 86% in 1992, down slightly from 88.9% when global production peaked at 100.3 million t.

The marine catch (and hence overall fish production) in 1992 was below the 1989 peak of 82.4 million t for the third consecutive year. This drop is partially accounted for by a large drop in the catch of the former Soviet Union.

As populations continue to grow (Fig. 1), especially in the developing world, and production from natural resources declines, the world is expecting aquaculture production to help bridge the supply–demand gap. World aquaculture production (marine and freshwater) doubled between 1984 (the first year with recorded global statistics) and 1992 to 13.9 million t (FAO 1992c). Potential global production is not readily estimated because new technologies and new enterprises will certainly push the potential up, within the limits of

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[3] The term *fisheries resources* encompasses those living aquatic resources taken for human use. As well as fish (teleosts and elasmobranchs), they also include invertebrates (echinoderms, crustaceans, molluscs) and plants such as micro and macroalgae. The plants are usually reported separately in statistics although their harvest and culture, particularly in Asia, is important, serving many food and other product uses. Unless specifically mentioned, aquatic plants are not included in the statistics quoted in the present paper. In 1992, 6.1 million t of aquatic plants were harvested, 5.4 million t of which were cultured.

[4] For example, Williams and Stewart (1993) pointed out that the Gulland (1970) estimate for Australian waters was approximately an order of magnitude too optimistic (over 2 million t predicted, but only about 200,000 t realized with development), due to extrapolations from regions with much higher primary productivity than that of the Australian Fishing Zone.

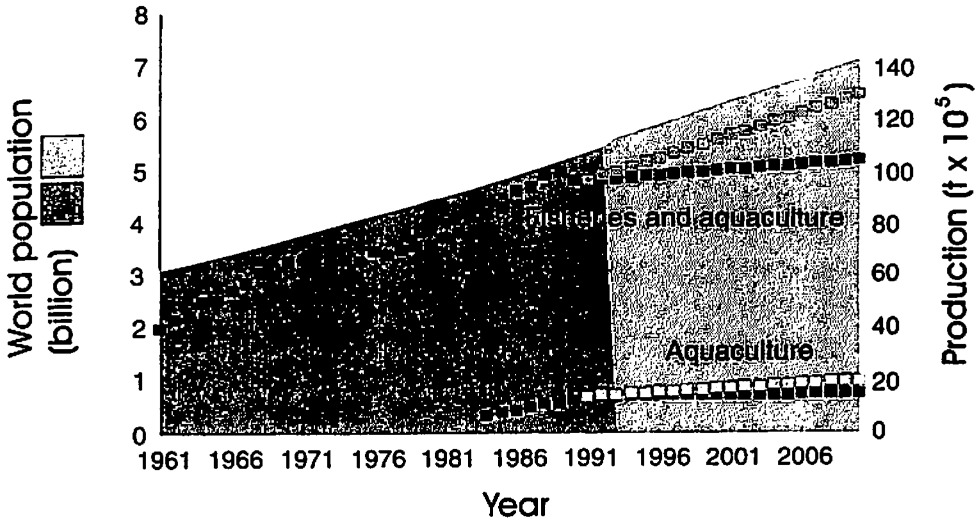


**Figure 1.** World population and fisheries and aquaculture production 1961–1992, with projections to 2010 (from FAO)

the natural resource base and access to it. In contrast to natural fisheries production, production from aquaculture could be greatly increased if care is taken in the expansion.

The downward trend for marine capture fisheries production is a cause for global concern and one which many countries and organizations have noted, also at the national level. At the global level of aggregation, it masks a range of important resource, trade and catch disposition trends within parts of the developing world.

From the late 1940s to 1970, annual marine fisheries production increased by 6% per year on average (Fig. 2) but fell dramatically after the collapse of the great Peruvian anchoveta fishery to only 2.3% per year (average increase 1980s decade). Much of even these smaller production increases over the last two decades has been due to an increased number of countries reporting catches to the FAO, a greater number of different species landed and an increase in the extent of waters fished. Catches of many of the species groups with the longest histories of harvesting, e.g., demersal fish, lobsters and sharks, have increased little over the last 20 years.

Production trends and potentials are only partially revealed by production statistics, since these are dependent on the amount of fishing effort applied and the capacity of stocks to sustain catches in the long term. Out of 200 fished stocks in all parts of the world, FAO revealed that over a quarter are overexploited, depleted or recovering and therefore would produce greater catches only if returned to a healthier state (Fig. 3). Thirty-eight per cent are

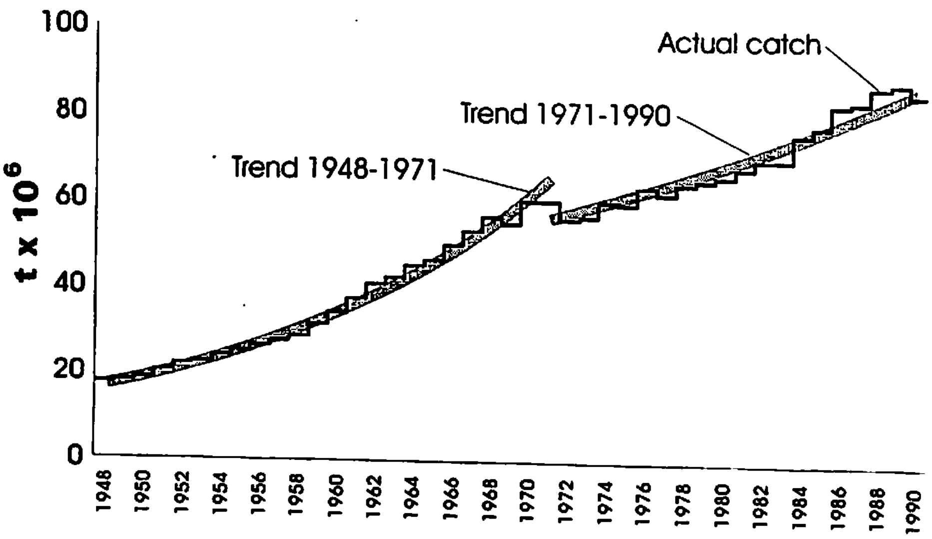


**Figure 2.** Growth in global marine catch (from FAO)

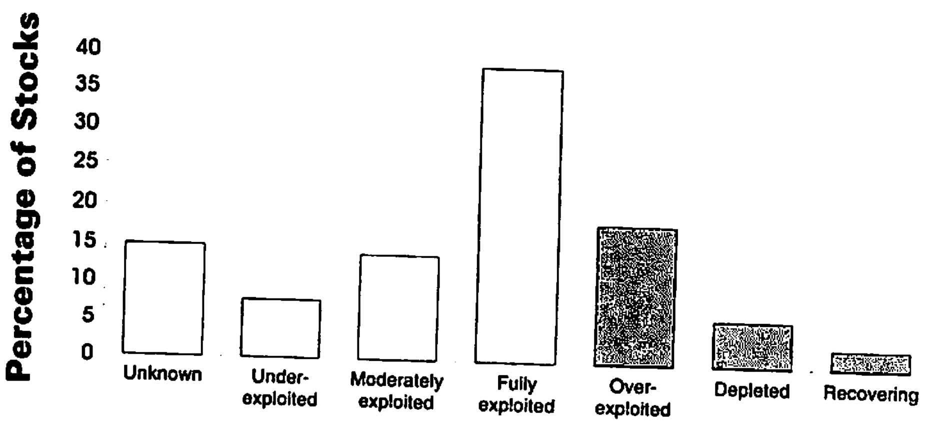


**Figure 3.** Status of the main 200 world fish stocks, 1990 (from FAO)

fully exploited and therefore cannot produce more catch without depleting the base stock; and only just over a third could produce more (FAO 1992b).

Over the three decades since 1961 and despite the near doubling of world population, the per capita supply (production for human consumption minus exports plus imports by country) of food (in calories) from fisheries and aquaculture has increased by over 70% in both the developed and developing world (Fig. 4). Average per capita consumption is already dropping, though the drop is more obvious in the developing world. At the same time, total food

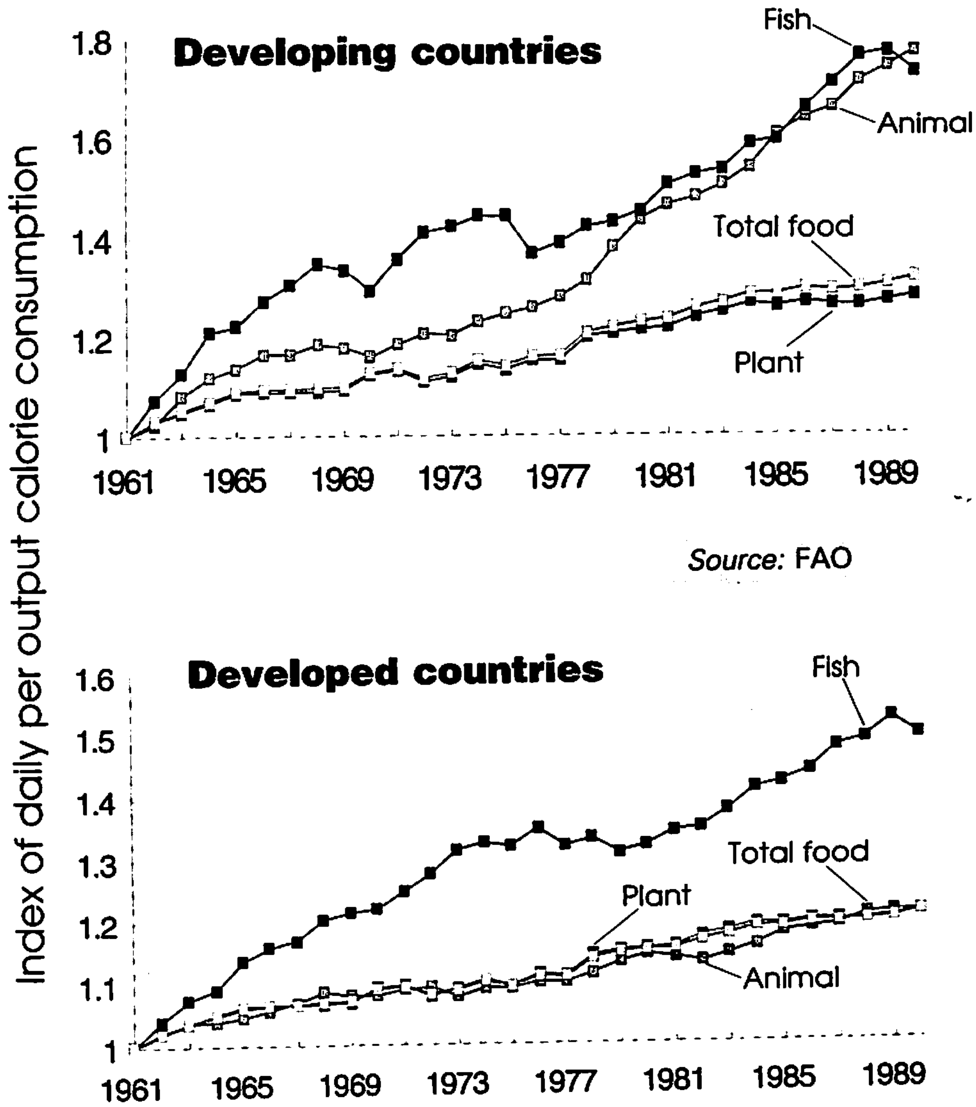


**Figure 4.** Indices of daily per capita calorie consumption, relative to 1961 (from FAO)

and plant food calories per capita have risen by less than 30%, and terrestrial animal food has risen by about the same percentage as that from aquatic products.

**The biological resource base**

Capture fisheries are the largest users of natural biological resources today. In theory, as abundance of a stock is reduced through fishing, compensatory growth produces a surplus (likened to the interest on the capital of the resource base) which we can sustainably harvest over time. In practice, estimating the capital base required to maintain the maximum interest or surplus production is difficult. Even if known, it fluctuates from year to year, species interact through predation and competition, and the capital is difficult to maintain when immediate social and economic pressures prefer to exploit not just the surplus but also the resource base.

High biodiversity at the generic, species and ecosystem levels is a key attribute of the living aquatic resource base. Over 5000 different species of fish and many hundreds of crustaceans, molluscs and echinoderms (see Table 2 for numbers of fish) are used directly, and many more species contribute indirectly through food and habitat support. The harvested species have a great diversity of life histories, from those which mature within months to those which mature later and live longer than humans, and with varying biology which affects their seasonal and geographic distribution, abundance and availability.

The great majority of species, however, are taken only in small quantities. In 1991, over 40% of the global production was made up of 24 species each having catches of 0.5 million t or more (FAO 1993b). Almost all species, including the 24 major species, are caught in association with other nontarget species. A recent study (Alverson et al., 1994) found that the annual global, nontarget and discarded marine fisheries catch is approximately 27 million t, a figure much higher than any previous estimates.

The complex composition of the resource base adds to the challenges of estimating sustainable production.

Fishing affects biodiversity but the impacts have yet to be investigated in any substantive way. The composition of marine communities often changes when the abundance of major fished species is reduced. For example, large food fish were common in the demersal communities of the Gulf of Thailand in the early days of fishing, but have now given way to small, short-lived fish and squid and shrimp communities (Pauly 1979; Boonyubol and Pramokchutima 1982); fishing out the top predators on coral reefs in Jamaica appears to have caused a population explosion of algal grazing sea urchins which later collapsed and permitted algae to overgrow the reefs (Done 1992; Hughes 1994). Overfishing is considered one of the three major anthropogenic factors affecting the degradation of coral reefs in all oceans; the other two are nutrient enrichment of reef waters from terrestrial runoff and sedimentation.

**Table 2.** Finfish used by humans

| | Species total | | Notes |
|---|---|---|---|
| | *n* | % | |
| *Extant finfish* | 24,618 | 100.0 | |
| Used in fisheries | 2,576 | 10.5 | Industrial and artisanal fisheries |
| Used in aquaculture | 179 | 0.7 | Commercially used for aquaculture, either for food or stock enhancement |
| Used as bait | 134 | 0.5 | Used as bait fish |
| In ornamental trade | 1,980 | 8.0 | Commercial ornamental species |
| Marine | 546 | | |
| Freshwater | 1,434 | | |
| Mainly bred | 773 | | |
| Used as sport fish | 798 | 3.2 | Sport fish |
| Total used by humans | 4,572 | 18.6 | Used in fisheries or aquaculture or as bait, ornamental, or game fish |
| *Finfish affected by humans* | | | |
| Threatened | 770 | 3.1 | Species reported to be threatened |
| Introduced | 221 | 0.9 | Transferred to and established in another country |
| *Finfish affecting humans* | | | |
| Dangerous | 437 | 1.8 | Poisonous, venomous, traumatogenic, etc. |

Note: Although FishBase does not yet contain all species, the above statistics should already provide a reasonable estimate, since ICLARM has made an effort to include all species that are used by humans. The number for Fisheries is underestimated because many species that are important in artisanal fisheries are not reported in the literature. The same is true for bait fish.

(from ICLARM FishBase as of 01/09/94)

Few marine species other than reptiles and mammals are listed as endangered or vulnerable, although many freshwater fish species are listed on national and international lists. The listings appear to reflect the relatively poor knowledge of marine biota; also that marine species may be more resilient to extinctions; and that most marine ecosystems have so far been less subject to wholesale change, fragmentation and removal than terrestrial systems.

Aquaculture production uses at least 181 species (Table 3), many native to their culture localities but with notable exceptions such as salmons, trouts, tilapias and carps which have been introduced widely to new localities.

Aquaculture has a long history on many continents, e.g., over 2000 years in China, over 1000 years in Europe, but until recently has not been subject to the same intensive development of its genetic resource base and culture practices as terrestrial agriculture.

**Table 3.** Summary of the commodity groups and species involved in the majority (>95%) of world aquaculture

| *Commodity Group* | *Total no. of species cultured* | *No. of species or higher taxa that account for >95% of that commodity group* |
|---|---|---|
| Seaweeds | 6 | 4 |
| Molluscs | 43 | 9 |
| Crustaceans | 27 | 7 |
| Finfish | | |
| Freshwater and brackishwater | 72 | 17 |
| Marine | 33 | 4 |
| TOTAL | 181 | 51 |

(from Pullin 1994. Original data and nomenclature and data from de Luca 1988, Taiwan Fisheries Bureau 1990 and FAO 1991.)

For example, fish genetic improvement is estimated to lag behind similar advances in terrestrial livestock by nearly 50 years (Eknath, Bentsen et al. 1991). Standard selective breeding techniques for enhanced production were begun with Atlantic salmon only in 1975 (Gjedrem, Gjerde and Refstie 1988) and for tilapia by ICLARM and partners only in the late 1980s. There is mounting concern that the genetic bases of many key species of cultured fish are deteriorating to the extent of lowering average growth performance (e.g., Eknath and Doyle 1990 for Indian major carps) or that the most common strains used may not always be the best (e.g., Eknath, Tayamen et al. 1993 for Nile tilapia strains in the Philippines).

Cultured aquatic species and natural stocks interact in many ways, including through biological competition between hatchery-reared and natural stocks in enhancement programmes (Hilborn and Winton 1993) and from escapees, and through dependence of some cultured species on fishmeal and fish oil in feed.

Species used in aquaculture cover the range from giant clams which obtain most of their nutrition from symbiotic photosynthesizing zooxanthellae (Munro and Gwyther 1981; Klumpp, Bayne and Hawkins 1992), herbivores (tilapias, milkfish and some carps), to high-level carnivores and omnivores (shrimp, crabs, salmon, trout). The trophic levels of many cultured aquatic species are much higher than those of their terrestrial equivalents, except goats and pigs. Feed conversion efficiencies in many cultured species are therefore at issue, although there is considerable scope for research to improve these. Tacon (1994) estimates that dietary fishmeal levels in aquaculture species will eventually be reduced to about half.

## The geography of production and consumption

Total catches from the developing countries have exceeded those from the developed countries since the late 1980s (Fig. 5).

By volume, fisheries and aquaculture production is remarkably concentrated. Since most production comes from natural resources, natural resource endowments and the extent of distant-water fishing are the major reasons for national and regional differences, although aquaculture development is also concentrated.

For total fisheries and aquaculture production, the top six countries (China, Japan, former USSR, Peru, Chile and USA) produce over half of the world's fish catch and the top 20 countries produce over 80% of the catch (Fig. 6). In

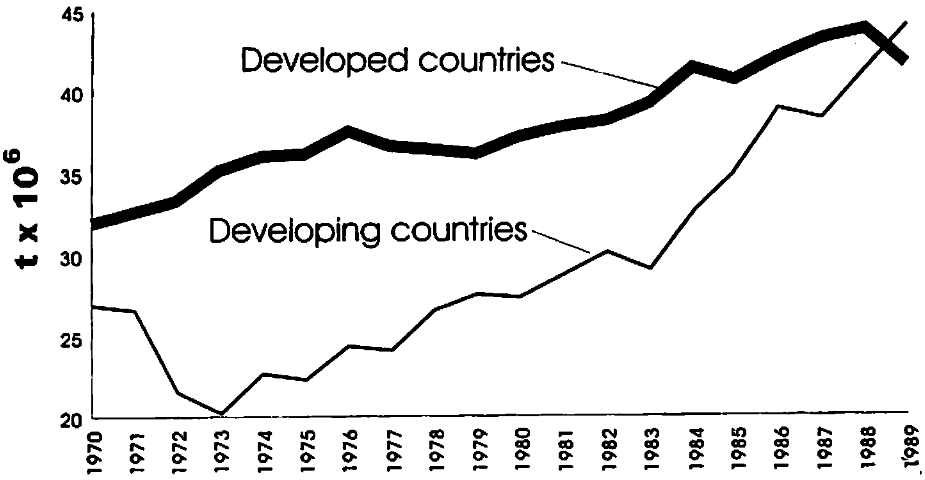


**Figure 5.** Total marine catch by developed and developing countries (from FAO)

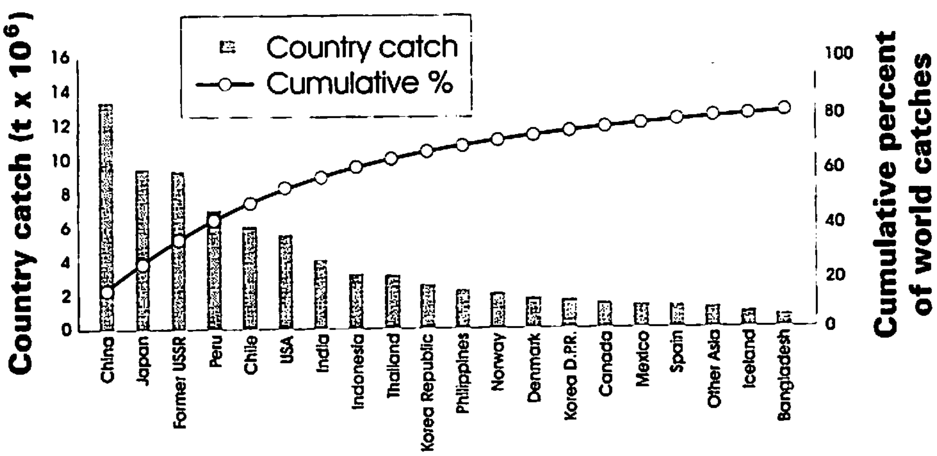


**Figure 6.** Total catch in 1991 (from FAO)

1991, the former USSR, Japan and the USA took 3.2, 1.0 and 0.2 million t, respectively, in nonadjacent waters (FAO 1993c).

A breakdown of total production by continents shows the dominance of Asia, in both marine and inland production (42.8% and 72.1%, respectively, of the global production) (Fig. 7).

On an ecosystem basis, the greatest primary productivity occurs in upwellings, coastal and coral reef systems, ponds and lakes (Figs 8 and 9). Pauly and Christensen (1994) have calculated that 8% of aquatic primary production is captured in products for human use. In coastal upwellings, tropical and temperate shelves, and in inland waters, 25–35% is taken up in the aquatic food webs leading to human use. Vitousek et al. (1986) calculated that for terrestrial ecosystems, 35–40% of total primary production was used by humans. Present human populations now use a large percentage of global biological production.

Most of the very productive aquatic ecosystems occur close to continents or land. Therefore, about 90% of capture fisheries production comes from coastal waters within the 200 nm zones of coastal states (Garcia and Newton 1994). Where country boundaries adjoin, however, many stocks are shared and thus fisheries production and its management have a geopolitical dimension.

Fish consumption is also geographically diverse, being highest in maritime countries with greater access due to their greater supplies; greater purchasing

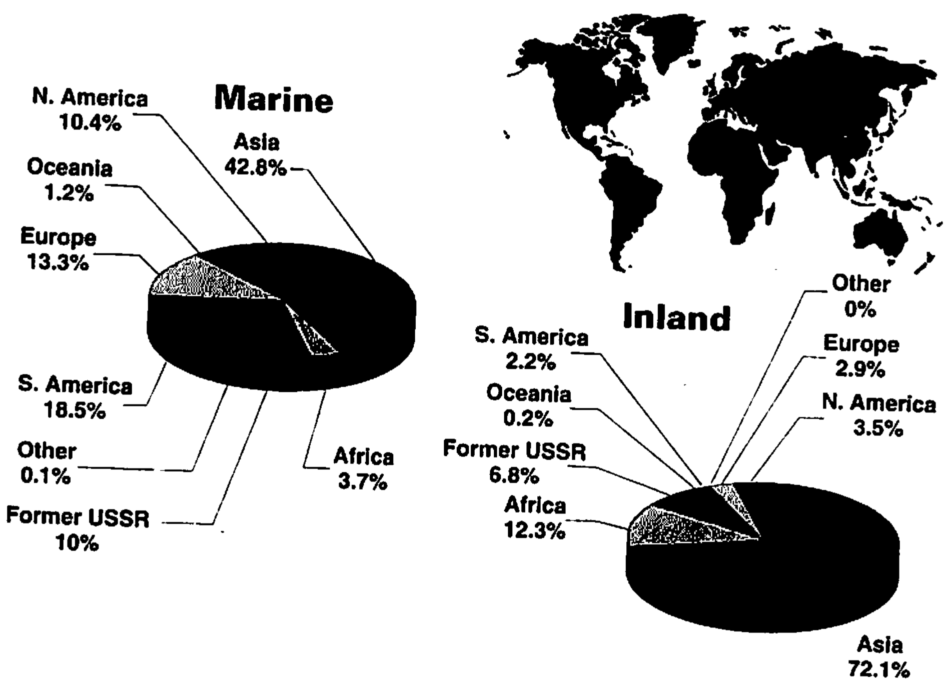


**Figure 7.** 1991 marine and inland fisheries production by continent

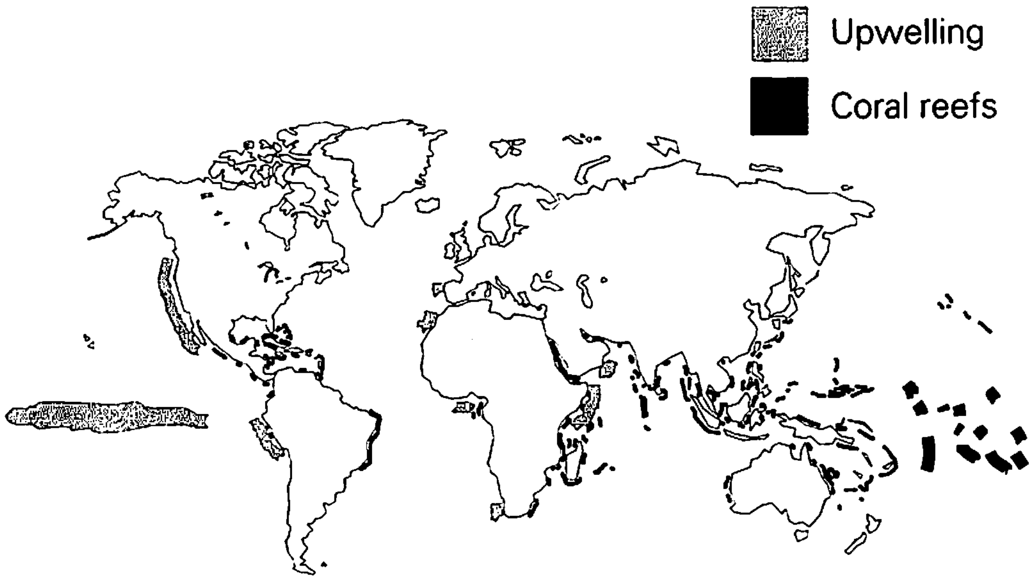


**Figure 8.** World map showing upwelling areas and coral reefs

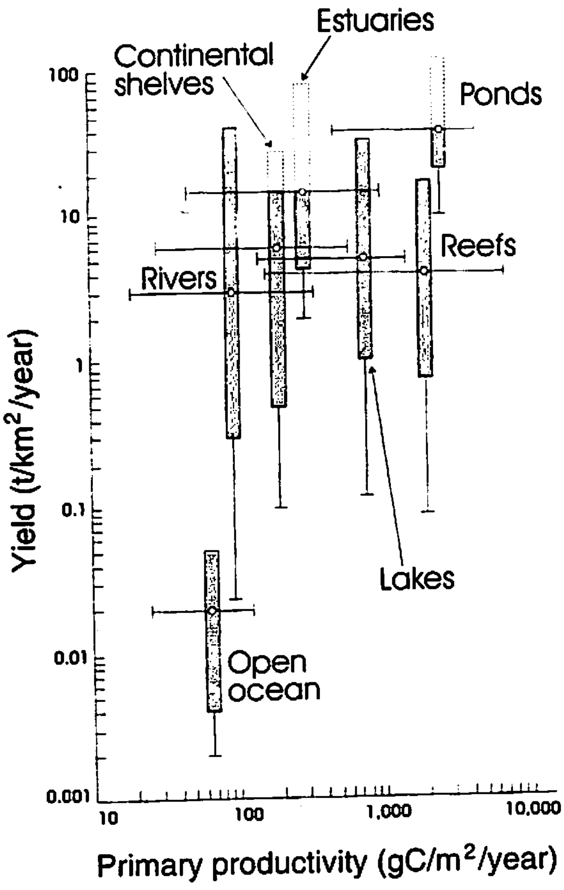


**Figure 9.** Ranges of yields in various tropical ecosystems

power; and/or fewer alternative sources of animal protein. Thus, the Maldives, Japan and Iceland stand out above all other countries. Consumption is more than 200 calories/person/day in these countries or nearly 10% of total food calories. Japan consumed 13% of the world fish catch for human consumption in 1991 (FAO 1993d). Relative to total animal protein consumption, people in Asia, Oceania and Africa consume more fish than those in the Americas and Europe.

### Economics of world fisheries

The biological outlook for many of the world's fisheries stocks is serious. Though not so well documented globally, the economic situation is also poor (Garcia and Newton 1994). FAO (1992a) estimated that the world fishing fleet increased at twice the rate at which catches increased over the last 20 years. Even more seriously, the fleet, overall, operates at a deficit of US$15,000 million even excluding return on capital from the operational costs. This is not surprising since fisheries economic theory suggests that maximum economic yield obtains from an exploited stock when fishing effort, and hence biological yield, is below that required to take the maximum biological yield (Fig. 10). The majority of the world's fished stocks are fished at effort levels greater than those required to take the maximum sustainable (biological) yield.

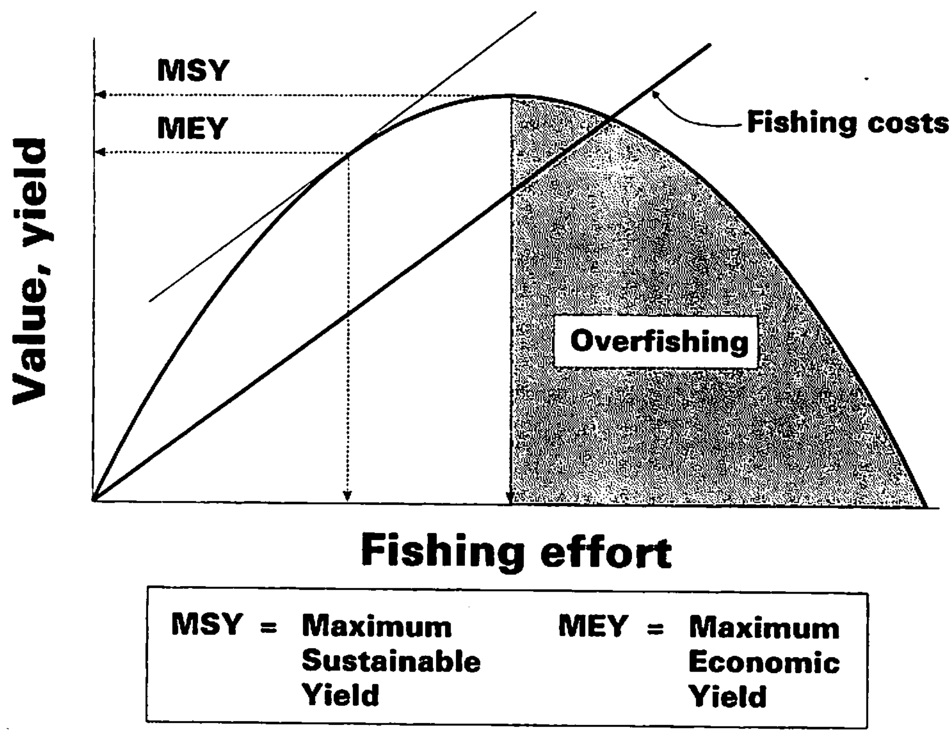


Figure 10. Biological and economic overfishing

Present fisheries operations at all scales are economically inefficient. Overcapitalization and economic overfishing are significant problems in world fisheries in both the developed and developing world (e.g., see Trinidad et al. (1993) for the Philippines fisheries for small pelagic species; Ahmed (1991) for the riverine fisheries of Bangladesh; and Solorzano et ãl. (1991) for the fisheries of Costa Rica). In the developing world, where lack of access to capital is a significant impediment to economic progress, scarce capital is used on too many vessels and too much gear. Fishing capacity is far in excess of that required to take the maximum sustainable yield and even further in excess of that required for economic efficiency.

Garcia and Newton (1994) presented a global bioeconomic analysis of world fisheries based on the 1989 catch and fleet. They concluded that further increases in fishing effort would barely increase the catch but would cause further declines in catch per unit effort. Further, they showed that the current fleet costs were so great that no amount of fishing effort by the fleet could produce a revenue to match the costs.

**Supply, demand and world trade**

Internationally, fisheries and aquaculture products are highly traded goods. Trade grew from 32% of world production in 1980 to 38% of world production in 1990 (FAO 1993b). By comparison with other agricultural commodities, only 4% of rice and 22% of wheat are traded.

However, both consumers and producers are disadvantaged by the cost structures of the sector. Garcia and Newton's (1994) study also concluded that fisheries resources are severely underpriced relative to the costs of catching. At 1989 fleet levels, prices would have to be raised by 71% for the world fishery to become economically viable. Alternately, costs would need to be lowered by 42% or some combination of raised prices and lowered costs.

The supply–demand gap is predicted to increase in the near future, and this will keep pressure on trade and prices. The FAO predicts that by 2010 world total fisheries and aquaculture production will be between 10 and 30% above current levels, supplying a world population 36% above present levels (FAO 1993b).

On balance, the developing countries export more, most of it to the developed countries, than they receive in imports and this trend is likely to continue (Fig. 11). This is the reverse of trade patterns in many other food commodities, especially cereals, where developing countries are net importers. Indeed, Carruthers (1993) argued that the developed, temperate world was on the way to being the producer of the bulk of the world's food while eventually the tropical developing world would be producing more of the manufactured goods. Developed countries will continue to be net importers of aquatic products in the near future unless they increase their aquaculture production

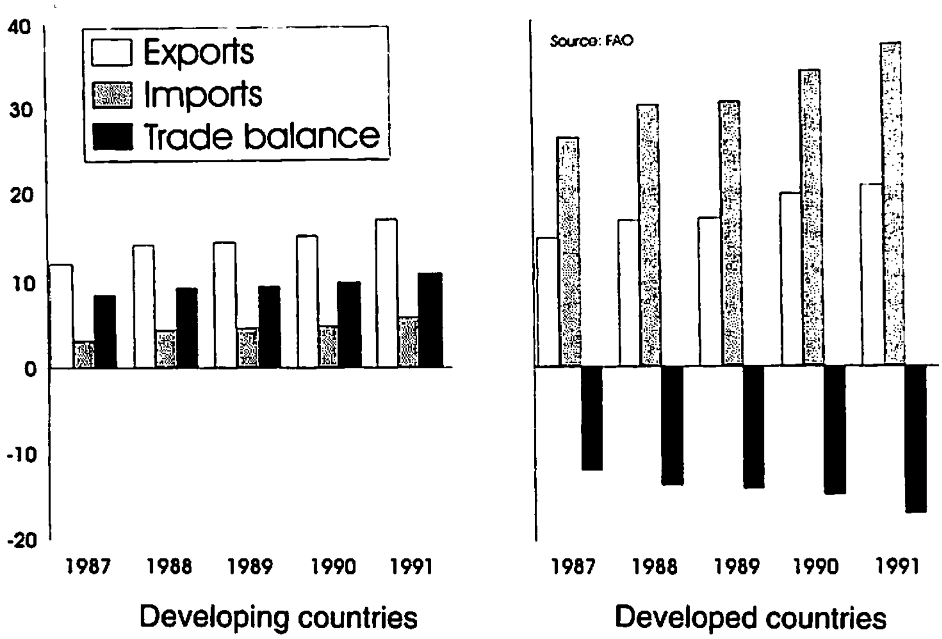


**Figure 11.** World trade in fisheries products (from FAO)

dramatically, or unless the overall production in developing countries declines sharply. This latter may well occur without better resource management.

Trade and the high economic value of some species will place additional pressures on developing countries to exploit their stocks and intensify their aquaculture. The pressures of trade on sustainable fisheries production in the developing world has not yet been recognized in the same way that it has say for tropical forest products. The International Tropical Timber Organization set the year 2000 as the target by when tropical timber exports should come only from sustainably managed forests. Several exporting and importing countries are discussing labelling and certification procedures (reported in FAO 1993d).

For some long-lived and slow-growing species such as sharks and groupers, the sustainable catch levels are low, whereas the economic incentives to take them may be high, causing a conflict between biological sustainability and economics. In purely economic terms, and if the harvesting costs are ignored, it only makes sense to conserve fisheries resources when their intrinsic per capita population growth rate exceeds the discount rate (or the bank interest rate) (May 1976). If this is not the case, it is economically optimal to take the whole stock and bank the proceeds.

In 1990, ten countries (Japan, USA, France, Spain, Italy, Germany, UK, Hong Kong, Denmark and Thailand) each imported more than US$1000 million of aquatic products. Thirteen countries exported more than this value in product (USA, Thailand, Denmark, Norway, Canada, "Other Asia", Korea, Netherlands, Iceland, Indonesia, China, UK, Chile and France) (FAO 1993b).

Prices of fish have risen faster than beef, pork and chicken since 1975 (Weber 1994a). Market demand is high but elastic. The elasticities of supply and demand between seafood and other types of animal protein such as chicken and pork are not well understood. Value-added seafood products are being designed to cater to the same convenience food markets as many other animal protein products, e.g., tuna burgers, various surimi products, fish fingers.

As market prices have risen, low-income fishers and fish farmers have started to sell more of their production in markets, and unless their own production increases also, must resort to consuming only smaller and/or lower-market-value fish in the household, thus lowering the quality of the fish they eat (Hossain and Afroze 1991; R. Brummett, ICLARM Malawi office, pers. comm.).

Many different species of fish are substitutable in the market. For example, white-flesh fish fillets may be sourced from temperate (e.g., European or New Zealand) species or from tropical cultured tilapias. Processed products such as surimi can use a wide range of white fish flesh.

About 30% of world fisheries production goes to animal feeds in agriculture and aquaculture (FAO 1993d). Chamberlain (1993) estimated that the world aquaculture feed market in the year 2000 will demand 4.6 million t of fish feed, 1.2 million t of fishmeal and 0.4 million t of fish oil, increases of 56%, 50% and 77%, respectively, on their 1990 values. These projections are based on the extrapolation of current production trends for the main cultured species and are therefore heavily dependent on using a high proportion of carnivorous and omnivorous species, e.g., salmon, trout, shrimp and catfish. With further research, however, the fish component of feeds could be substantially reduced and replaced with vegetable proteins. The projections also would be different if a greater share of the increased production were to come from herbivores such as tilapias.

Marketing of seafood is challenging because of its seasonality, perishability and variety of species. The challenges and opportunities are addressed internationally by a comprehensive global trade information system (comprised of the GLOBEFISH, INFOFISH, and other networks), unmatched by any other food commodity network. To date, only one product, frozen, headless white cultured shrimp, has been sufficiently standardized to provide a futures market.

### The people in fisheries and aquaculture

Population growth, social, cultural and economic organization have also shaped the present transition in fisheries. Weber (1994a) estimated that 14–20 million people were involved directly in small-scale fishing, and ICLARM (1992) found that about 50 million were involved in the whole sector. In villages, towns and cities, many more depend on the products for food. Employment in the fisheries sector has grown with coastal communities, and it is very dynamic because of the mobility and seasonality of the resources, technological developments and interactions with other sectors, especially other rural sectors.

In most societies, small-scale fishers have low social status and few options for livelihoods. In developing countries dominated by the agricultural sector, many are technically landless. Fishing is often one of the last occupations people can enter when other options in agriculture or manufacturing are closed. Small-scale fishers require minimal gear or can sell their labour to larger operators. Access to resources has usually been free, but the entitlements of this access are ill-defined and tenuous. As the resource degrades, fishers are often left with little. Even farmers on small holdings have greater stability of tenure over the means of production and hence nutrition and/or income generation. The competitive nature of many fisheries, especially under scarcity, makes cooperative social investment more difficult. Putnam (1994) has shown that economic development may be linked to the accumulation of so-called "social capital" in a society.

Small-scale fishers have little political influence compared to large-scale fishers and other sectors of the economy. Pauly (1994a) described the marginalization of small-scale fishers. Their interests are frequently ignored in major policies and decisions. For example, fishers and fisheries resources appear to have been ignored almost completely, or received too little attention, in major recent initiatives such as the Pak Mool Dam in Thailand (Sukin 1994), in the Bangladesh Flood Action Plan (Pearce 1994) and in the World Bank discussion paper on an environmental strategy for Asia (Brandon and Ramankutty 1993).

Fishing is overwhelmingly a male activity in most of the developed and developing world. With few cultural exceptions, women's roles are in shellfish gathering and postharvest activities such as processing, transport to market, selling and buying. Women's opportunities to participate in fisheries and aquaculture activities are governed by their permitted social roles and present commitments. For example, Hviding (1993) found no women enrolled as participants in village trials for giant clam culture in the Solomon Islands, causing him to speculate on how this situation could be changed but also remarking that these women had little spare time due to their other duties in gardening, gleaning, collecting firewood, etc. In Bangladesh, however, women usually are not permitted to do a range of field work or to go to the markets, thus leaving them with some spare time for fish husbandry. Some ICLARM trials in small-scale pond aquaculture in Bangladesh have had up to 60% women participants.

All scales of fishing from artisanal to large industrial-scale are dangerous due to a combination of vessel configurations and difficulties of working complex and cumbersome gear in the dynamic aquatic environment (McGoodwin 1990; Warner 1983). In the developing world, desperate, poverty-driven, destructive fishing practices are common, including dynamite and cyanide fishing, and boats run by absentee boat-owners who use poorly paid, very young fishing crews. These sometimes create demeaning and dangerous physical conditions more akin to the darkest days of the industrial revolution and the pearl diving industries of the late 19th and early 20th centuries than the last decades of the 20th century.

**The environment and climate**

In common with other biological production industries, fisheries and aquaculture are intimately dependent upon climate and the environment. In many parts of the world, especially the developing world, environmental quality is deteriorating, inevitably affecting production potentials. Some fisheries and aquaculture practices also contribute to the decline in the quality of the environment. Laevastu (1993) pointed out that natural fisheries resource fluctuations may be caused by fishing, ocean climate, the effects of pollution and other human activities as well as ecosystem processes like predation and disease.

Aquatic ecosystems are generally less well understood than their terrestrial and atmospheric equivalents. A key environmental concept is that of the functional integrity of the resource system, particularly that required to maintain habitats and sustain production. For example, compared to terrestrial systems, we have little understanding yet of what forms of habitat destruction and modification lead to loss of habitat integrity in aquatic systems. Whereas terrestrial systems are usually considered to be structured around relatively immobile features such as soil and higher order vegetation (trees, grasses), aquatic systems may generally be structured by more mobile habitat features such as phytoplankton and zooplankton, water temperature, quality and current regimes. Aquatic systems based on large sessile features, such as reefs, mangroves and seagrass beds, have habitat features more akin to those in terrestrial systems.

The connectivity between aquatic systems is far greater than between terrestrial systems, so that the impact of events in one part of the ecosystem can spread rapidly to other parts of the system. Aquatic systems are the eventual sinks for all terrestrial and atmospheric pollutants.

Contamination from heavy metals, organic and inorganic chemicals and harmful algal blooms (Hallegraeff 1993; Maclean 1993; Corrales and Maclean 1994) is increasing worldwide, in the developing as well as developed world, leading to large economic and food losses and some loss of lives. Most aquatic organisms have fragile, planktonic egg and larval life stages in which they are particularly sensitive to environmental pollutants.

Fished stocks are large and important components of their aquatic environments. Generally higher up the trophic chain than terrestrial animal equivalents used for food, they average two full steps from primary producers.

Direct removals by fishing will therefore change natural systems. Many fishing practices modify habitats in their course: e.g., bottom trawling removes some living communities, disturbs sediment and catches many incidental species; deployment of fish aggregating devices to attract pelagic (surface and midwater swimming) species such as tunas and mackerels. Aquaculture can also pollute the environment, affecting its own viability and that of surrounding agricultural systems.

Aquatic systems, which cover more than 70% of the earth's surface, have major influences on global climate through the hydrological cycle (heating and cooling the environment through its various foams as vapour, clouds, liquid, snow and ice) (Chahine 1992) and their part as sinks of about one-third of anthropogenic carbon dioxide (Siegenthaler and Sarmeinto 1993).

Aquatic systems themselves are influenced by climate and climate change. The 1982–83 El Niño, for example, raised sea surface temperatures by 5°C in some parts of the Pacific, limiting primary production and causing large changes in fish abundances (from Laevastu 1993). The impact on global fish production of the present protracted El Niño event, which commenced in 1991–92, has yet to be examined. Inland pond aquaculture is related directly to climate, especially rainfall and temperature, stream runoff and general water availability in a similar way to the link between agriculture and climate.

**Postharvest**

Most aquatic products are highly perishable and postharvest losses can be high, especially in the developing world where infrastructure (ice plants, freezers and processing plants) is often inadequate. Drying is the chief method used for long-term storage in low-income communities. Action which minimizes postharvest losses and deterioration will help improve the supply of aquatic products.

Many aquatic products command different market values depending on the form in which they are sold. The price per kilo for one species can vary by up to three orders of magnitude depending on whether it is sold live, sashimi (raw), frozen, dried, fresh or canned. Often the least postharvest processing (e.g., live or sashimi) obtains the highest price. Few other food products have the same plasticity and therefore opportunities for adding value even without increasing production.

## Five cross-cutting issues for the transition

The above section describes the present situation forcing the transition in world fisheries and aquaculture. To anticipate the outcomes of the transition, we must address the questions of utilization, resource management, intensification, integration with other sectors, and national versus international interests.

These issues are relevant for all countries and resources and they interact with each other. For example, options for better utilization are of no value to a small-scale fisher who has no security of access to those resources. International markets and trade will play a big role in how resources are eventually used; interactions between fisheries and other sectors in the coastal zone will affect access rights and can limit options for use; and new technologies from international sources will have a big influence in new options for use and for intensification of aquaculture.

**Options for utilization**

Living aquatic resources, presently mainly directly harvested for human food, offer perhaps the greatest range of potential uses of any biological resources. Taking advantage of the great range of possible uses of aquatic life, the best possible economic, social and cultural use of the resource should be sought. Much greater economic value may often be obtained from a given quantity of resource depending on how it is used. Table 4 lists possible uses of living aquatic resources and rates them according to economic and cultural values and employment prospects in the developing world.

We need to keep open minds on how best to use living aquatic resources for sustainable food security. We can use them directly as high quality food and indirectly for other economic ends such as livestock and aquaculture feed, crop fertilizer, jewellery (pearls, shells), recreation (game fishing, diving, ecotourism on coral reefs), food additives (carageenan from macroalgae), additives in the production of food, cosmetics, shampoo, detergents and industrial lubricants (macroalgae), via the application of marine biotechnology, as the base for production of a large range of industrial, medical and other chemicals, and for environmental protection such as mangroves which protect tropical coasts (Table 3, Norse 1993).

Nonfood uses are of two types: those such as fishmeal which obtain lower prices than fish sold for human food, and those which fetch higher prices than human food, such as pearls. As a contribution to food security, the latter are usually more important than the former, although the former also have an indirect contribution. The critical question to ask of lower priced uses is whether a greater contribution could be made by using the resources more directly for human food or for some other higher-priced alternative.

As price and demand increase, more pressure could result in the use of bycatch from industrial fleets for human consumption. The projected high demand for fishmeal and fish food for aquaculture could diminish if plant protein substitutes develop rapidly. Alternately, demand may be difficult to meet if more of the fish go to human consumption. Most of the catch for fish food and meal is of small schooling pelagics caught in large quantities. These are difficult to preserve quickly and safely except in industrial-scale operations. Technology and market price shifts could change this.

**Table 4.** Possible uses of living aquatic resources by peoples in the developing world: economic returns and employment prospects

| *Use* | *Economic & cultural value* | *Employment prospects* |
|---|---|---|
| *Extractive* | | |
| fishing for human food | *-*** | *-*** |
| fishing for animal feed | * | * |
| gathering for traditional medicines | *** | * |
| gathering for jewelry and ornaments | *** | *** |
| gathering, culturing for ornamental/aquarium trade | *** | ** |
| bioprospecting for new chemical uses | *-*** | * |
| aquaculture for human food | *-*** | *-*** |
| culture for industry additives (food, cosmetics, lubricants, etc.) | ** | ** |
| recreational and sport fishing | *** | *** |
| oils | | |
| chitin | * | * |
| leather, skins | *** | ** |
| *Conservation uses* | | |
| marine protected areas | *-*** | * |
| ecotourism, diving, underwater photography, whale watching | ***? | ** |
| tag and return gamefishing | *** | * |
| in-situ resource conservation | *-*** | * |
| *Environmental services* | | |
| biocontrol in ponds, rice fields | * | ** |
| diversification of small-scale agriculture: improve farm productivity and reduce risk | * | *** |
| integrate aquaculture with agriculture to improve on farm resource cycling | * | *** |
| integrate aquaculture with agriculture to improve soil fertility, crop productivity | ** | *** |
| biofilters in polyculture | * | * |
| *Cultural services* | | |
| religious value | *** | * |
| national icons, identity | *** | *-*** |

The number of *s indicate the approximate importance of each use. Where a range is shown, this indicates that the importance varies with particular uses.

Another dimension of use in aquaculture is the timing of returns on investments. An example where a use other than for human food brings earlier returns comes from ICLARM's clam research, which shows that cultured giant clams in coral reef lagoons take about seven years to reach the best size for the high value adductor muscle market in Asia. At 6–12 months, however, they can be harvested and sold to the marine home aquarium trade, and at 24 months for sashimi, thus bringing in earlier cash flows for village producers. The impact on food security is positive, since any losses to the Hong Kong restaurant trade will not result in starvation, but rather the village producer has money to buy staple foods or to reinvest.

Reducing postharvest losses is a direct and immediate way to improve usage. Losses can be minimized by better handling of natural product and development of aquaculture species and strains which transport better to markets or the home table. Reduced losses will also improve predictability and stability of supply. Donor agencies and national investors should make more development investments in small-scale postharvest operations than fishing vessels and gear. However, the scale of infrastructure investment for postharvest handling should match the size of the resource it has to handle. Large freezer plant, like large fishing vessels, are inappropriate if the resource base is modest.

Markets affect the disposition of aquatic production and, since they drive the economic value of production, will also drive the utilization of resources. Market demands are changing rapidly, whether these are in the household which consumes the product of the small-scale fisher or pond operator, the market in the local village or nearest city, or the export market.

As more fish is sold by the small-scale producer, the impacts on household nutrition should be studied. IFPRI studied the impacts of agricultural commercialization on household nutrition (reviewed in Kennedy and Bouis 1993) and showed that increased income did improve nutrition but usually at a lesser rate than expected. The studies recommended that health, education and sanitation programmes were necessary adjuncts if the family's nutrition and health were to benefit fully from the extra income. Similar results would likely be found for fishers' households. Also, replacing fish by purchased grains in the diet may lower protein and trace element intake (e.g., vitamin A). In small-scale aquaculture, Gupta and Rab (1994) showed that introduction of fish farming in Bangladesh could both increase household food supplies and provide a surplus for sale, thus helping household nutrition and income.

Not only markets but also public opinion can dictate the use or protection of some resources and the means by which they may be caught. Marine mammals are now protected in most countries, whales almost totally. Marine reptiles (sea turtles, crocodiles and sea snakes) are increasingly protected, though crocodiles are proving good for farming. Cambodia, for example, now has 120 crocodile farms. High seas drift netting will be phased out by 1995 after a concerted public campaign by conservationists in the early 1990s. Some groups are now calling for a complete global ban on trawling (Embrado 1994).

Conservation status can also reduce the options for use if a species or group is listed as endangered, vulnerable or threatened under the Convention on International Trade in Endangered Species and/or under any similar national legislation such as endangered species acts.

Alternative uses have some significant prospects for improving national economic welfare and a few have prospects of improving household welfare. Zilinskas and Lundin (1993) reviewed the prospects for marine biotechnologies in developing countries and developed related technical manpower and technology requirements (Fig. 12). Many alternate uses, including fishing with alternate gear, conflict with each other. Careful decisions will need to made of the best uses. For example, competing uses of the limited shark resources of the Maldives come from different fishing gear and between fishing and tourism for shark watching (Anderson and Ahmed 1993).

Employment prospects are mixed and difficult to predict, since they depend on the scale of operations developed, the technologies used and the level of uptake. For example, one of the most promising knowledge-based biotechnologies is small-scale integrated aquaculture-agriculture. The total fish production from these enterprises may not be large, but household food security could be improved, because farming systems and biodiversity studies are indicating greater total productivity and stability is obtained in more diverse, integrated farming systems (Guo and Bradshaw 1993; Baskin 1994).

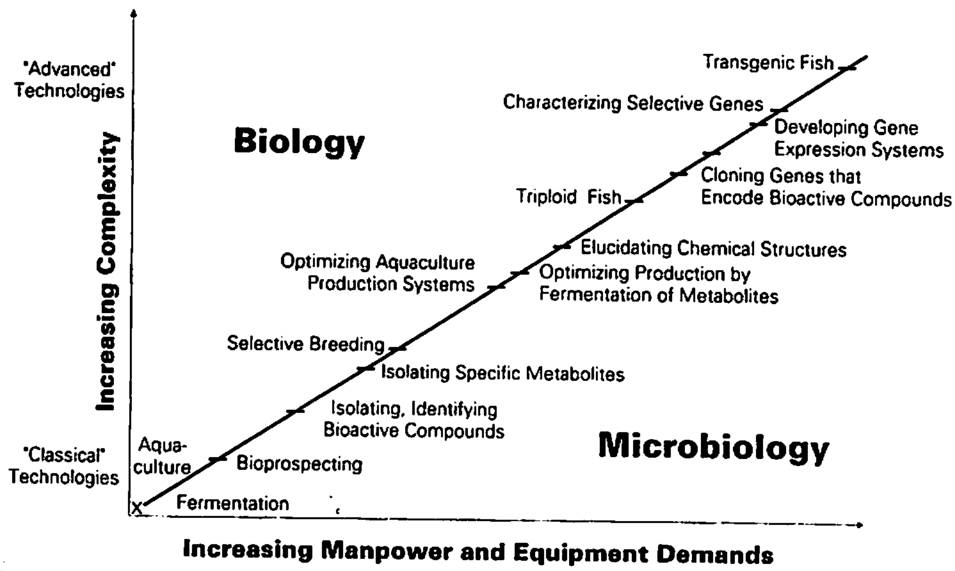


**Figure 12.** Gradient of marine biotechnology (from Zilinskas and Lundin 1993)

**Resource management—coordination, restraint and scarcity**

Natural fisheries resources are classed as commons—they are not owned by individual consumers but are shared by many, who extract private goods from them. But there is a limit to the goods which can be extracted, and the rate at which goods are appropriated affects the rate at which the resource can continue to produce its goods. Coordination and restraint are required to prevent individuals continuing to exploit the resource beyond sustainable limits (Oakerson 1992) and thus producing resource scarcity. Homer-Dixon, Boutwell and Rathjens (1993) recognize three causes of resource scarcity: change in resource levels; population growth causing reduced per capita availability; and the unequal distribution inducing scarcity for some users.

Many fisheries resource management arrangements have not succeeded in their tasks of coordination and restraint. They have not kept pace with the technological ability to exploit the resource, nor with the driving incentives to exploit: economic returns, population needs, food and employment. Management systems traditionally concentrated on fisheries development and resource management but failed to address the problems of economic efficiency, equity in sharing the benefits of the catch (Emmerson 1980), and conflicts among different types of users. Most systems have only belatedly recognized the importance of resource users in the management process, and few yet take the consumer into account.

A central cause of overexploitation in capture fisheries is the lack of any restraint on access. Open access often leads to resource overuse and economic inefficiency. There has been some confusion between "open access" and "common property management" since Hardin (1968) equated open access to "the tragedy of the commons", thereby focusing on the creation of individual property rights rather than limitation on access. More recently, Gibbs and Bromley (1989) pointed out that common property management where joint rights exist is a legitimate form of management and can be successful if access is controlled. In developed-country fisheries, the limiting of access has led to schemes to limit the number of fishers by regulated licensing and input restrictions (e.g., on gear, vessel size and days fished) and the creation of output restraints such as quotas which may be granted or sold as quasi-private property (e.g., individual transferable quotas). Despite a high degree of regulation, many developed-country fisheries are suffering overexploitation and there is increasing evidence of poor compliance with management regulations.

Few of the usual input and output regulatory measures are practical in small-scale fisheries in the developing world. Even when access is restrained, most fisheries still have excess numbers of fishers who can now claim legitimate access to the diminishing resources. Much more needs to be done to find other activities for users. Many small-scale fishers also pursue activities other than fishing, often in the agricultural sector. A recent World Bank study highlighted the lack of attention to managing redundancy in overexploited fisheries and drafted terms of reference for a working party on fishery exit (John 1994). This work should be followed up immediately because there is a growing need to find alternate livelihoods for those now depending on diminishing resources.

Equity is an important dimension of resource access and exit. In the developing world, small-scale fishers frequently lose out to industrial-scale operators favoured by national governments because of their contributions to markets, exports and the national economy. Weber (1994a) estimated that small-scale fishers caught nearly as much fish for human consumption as large and medium-scale fleets. The issue of which groups of fishers get or retain access should be examined from all angles: equity, resource conservation, economic efficiency and cultural values. Some of the other values, such as economic efficiency, may have to be traded off for equity.

That coordination and restraint in resource use has failed is revealed by the increasing scarcity of resources and the growing level of conflict. Conflict often revolves around rights and their distribution. Declines in the resource exacerbate conflicts among users, from the local to the international (e.g., in the Philippines (Luna in press); in Asia (Richardson 1994; Cushing 1988)).

Recognizing that conflicts will escalate with increasing scarcity of resources, we need more ways of preventing and resolving these conflicts before they escalate into civil violence. The early solution was to use scientific advice on the state of the stock and institute national fisheries management plans. Cushing (1988) reviews the history. Such solutions offer only partial answers. Many are now suggesting that conflicts can be diminished, management better implemented and resources therefore better managed when user groups help develop resource management options through comanagement with state-level authorities (Pinkerton 1989; Berkes, George and Preston 1991; Pomeroy 1994).

However, the way ahead to better resource management is not clear, and a global research project has begun to investigate the application of comanagement practices and potential in various resource and sociopolitical settings (Pomeroy 1993). For example, Kuperan and Abdullah (1994) examined Southeast Asian countries and ranked the Philippines as most likely to successfully adopt comanagement practices, and Indonesia, Papua New Guinea and Thailand as having a moderate chance of successful adoption.

Over the last decade, the community has become increasingly important in fisheries management in most countries. Devolution and decentralization of authority is formally giving local-level citizen groups more responsibility and say. Decisions are brought down to levels more appropriate to the functioning of the resource and social systems. In some systems, this may have been a belated recognition of former tenure arrangements which were disturbed when central governments first formulated fisheries acts in the middle decades of this century. In all cases, community involvement is happening at a time of diminishing resources, and it is important that users now get an opportunity to influence the future options. A big question is whether these options will help conserve and rebuild a degraded resource for future generations or simply defuse the immediate conflict.

Coordination of fisheries with other sectors is only now being recognized as vital to the future of small-scale fishers and fisheries, although Emmerson (1980) warned of its importance. Therefore, alternative livelihood projects which have started in countries such as the Philippines could play a role in food security for those fishers who remain, as well as helping some exit altogether and obviating the need for others to enter.

Inland aquaculture faces different issues in natural resource management, especially in access rights. Small-scale farmers with entitlement to their land have greater security of tenure than capture fishers. But the farmer will have to compete for scarce water resources with agriculture, urban and industrial users. In many regions, rainfed supplies could suffice. Small farmers in the developing world are a potentially vast source of new entrants into integrated aquaculture-agriculture, e.g., in rice-growing parts of Asia and in large tracts of Africa.

In small-scale fish farming, even landless people can find employment and some limited access to the means of production in many cultures, often with the help of socially conscious nongovernment organizations (NGOs). With the help of local NGOs in Bangladesh, early results of studies into the feasibility of small pond fish culture by functionally landless people were outstanding. Groups of women and landless day labourers have raised good crops and returned profits relative to the small investment in inputs, using leased ponds, roadside ditches and rice paddies (Gupta and Rab 1994; Gupta, pers. comm.).

Coastal aquaculture will face severe competition from other resource users for suitable sites and will therefore experience some of problems of common property resource management. The growing concentration of large urban centres and populations in the coastal zone (more than half the world's population, and more in some regions, lives within 100 km of the sea) reduces the quality of the environment as well as increases the competition for access. Like fishing, coastal aquaculture will have to find its voice in integrated coastal zone management. This is always easier for the larger, more intensive enterprises such as intensive shrimp farming, which rapidly took over many parts of coastal east Asia, encouraged by large export market returns.

### Intensification

Pinstrup-Andersen and Pandya-Lorch (1994) have argued that agricultural intensification or greater production of food on the present cultivated land is essential to alleviate poverty. Terrestrial environments are most commonly degraded by people driven by poverty to overexploit natural resources.

In the case of harvest fisheries, economic incentives, technology developments, ignorance of the limits and poverty all contribute to intensification of exploitation (i.e., increasing and more effective fishing effort), which, up to the limits of sustainable production, is the main means for increasing production of these resources. Beyond the limits, however, yields begin to fall as the productive capacity of the resource declines (see Fig. 10). The limits of sustainable exploitation are reached rapidly with mechanization and deployment of industrial-scale fleets, but they can also be attained when the number and capacity of small-scale fishers is too great relative to the sustainable level of production. The limits have frequently been exceeded in fisheries because management action and scientific knowledge have not been able to keep pace with the rate at which exploitation intensifies.

The limits to intensification are inelastic in capture fisheries. Indeed, Pauly (1994a) has pointed out that while we still largely depend on natural fisheries stocks, Malthusian concepts on the relationship between resource levels and human needs are relevant. Capture fisheries production is subject to limited human control, consisting of management of the quantity, size and timing of the catch, minimization of negative human impacts on biological processes (breeding, migration, feeding, etc.) and the environment and, for certain species, enhancement of wild stocks through reseeding. Incidental nutrient enrichment of waters through pollution has apparently enhanced fisheries production in some areas such as the Mediterranean (Caddy 1993).

Paradoxically, production could be increased from some capture fisheries by reducing the intensity of exploitation to allow recovery of the resources, or by targeting fishing onto larger fish and thereby increasing yield per recruit. Protection of some areas as reserves could enhance production in adjacent sites and may stimulate higher total production.

Destructive fishing practices such as dynamite, *muro ami* fishing (herding of fish into giant nets while banging numerous rocks across the top of a coral reef) and cyanide fishing are common examples of inappropriate intensification, driven by poverty and leading to massive environmental degradation. McManus (1993) has described these "Malthusian overfishing" practices and their impacts on coral reefs.

Unlike their counterparts on the land, many living aquatic resources were long protected from extensive use and intensification by the difficulties of working at sea. This protection was eroded drastically over the last few decades by technological advances, including the advent of industrial-scale fleets using new fishing and fish-finding gear, and the huge population explosion of this century.

In short, intensification of exploitation of capture fisheries only yields greater production up to a limit. To set and control fishing intensification within the limits, managers need good scientific knowledge of the stock status and carrying capacity of the environment, appropriate management schemes, and good monitoring and compliance measures. Many of these conditions are not met for the majority of small-scale fisheries.

Many forms of intensification hold considerable promise for increasing aquaculture production. However, great care is needed as we already have some examples in the developed and developing world of culture practices which have intensified inappropriately and caused severe environmental damage as a consequence. In addition, some forms of aquaculture are suffering one of the most common early effects of intensification—chronic disease problems.

Aquaculture production is governed by a similar range of environmental, climatic, resource (space, inputs, labour), pest, disease and technological constraints as agricultural and livestock production. However, land and suitable quality water are increasingly scarce; competition with other users for suitable land, sites and water will hamper aquaculture production increases. New culture technologies and new ways of sustainably integrating aquaculture with other land uses such as agriculture will be required to produce sustainable resource systems.

Intensification of shrimp (marine prawn) culture in several Asian countries (Taiwan, China, Indonesia, Thailand, Philippines) led to severe environmental and disease problems resulting in production crashes from which many sites have not yet recovered (*NACA Newsletter* 1994). Inadequate scientific knowledge of the consequences of many of the farming practices, outbreaks of existing and new diseases through poor hygiene and quarantine, and lack of control over pond effluent intakes and outlets all contributed to many farms suffering irreversible crashes in production, some after only 2–3 years of production. Some, such as those in Taiwan, where production fell from over 80,000 t per year in 1987 to very limited production in 1991 (FAO 1992c), have not recovered.

Two forms of production intensification are halfway between wild fisheries and aquaculture. The first is stock enhancement, wherein hatchery-reared or captured fry, larvae or seed are placed into a natural environment for grow-out and harvested later as wild stocks. The success of such schemes is still being debated (Hilborn and Winton 1993; Munro 1994), including the impacts on genetic diversity of wild stock. The second is cage, pond or rack grow-out of collected juveniles, especially of high-value species which can be sold in peak condition at the top of the market. Both forms are suitable for some low-input systems. This former technology with giant clams has been pioneered successfully in the Pacific (Fitt 1993). In the Solomon Islands, ICLARM and the Australian Institute of Marine Science (AIMS) are starting a project to study the enhancement of reef fish production using light trapping technology developed at AIMS. Blacklip pearl oyster production in the western Pacific relies on enhancement technology (i.e., natural spat collection), partly to protect the remnant wild stocks which have not recovered from overexploitation by foreign parties nearly a century ago (South Pacific Commission 1994).

**Integration**

Fisheries and aquaculture sectors cannot be considered in isolation. To anticipate the possible consequences of the current transition, greater recognition must be accorded the integral nature of fisheries resources and aquatic ecosystems, natural or artificial, of aquatic and terrestrial systems, of fishers and fish farmers in the economic, cultural and political fabric of their communities and nations, and of the effects of climate and climate change. For too long fisheries and aquaculture have been treated as sectors in isolation, a practice which has ignored important linkages and externalities.

Many of the problems and solutions to fisheries problems lie outside the sector, in overall community and economic development (Smith 1979; Johnston 1992) and vertically integrating small-scale fisheries development could escalate problems (Emmerson 1980).

Capture fisheries productivity depends on biological resource endowments and processes, extent of fishing pressure, habitat integrity, quality of the environment, weather and climate. The human side of the fishery is the sum total of the people, their fishing equipment, the institutions of the market and postharvest handling, political and cultural rights and regulations governing use of the resource, and the relevant micro- and macro-economic settings.

The schema developed in Scura et al. (1992) (Fig. 13) for integrated coastal zone management shows the complexity of issues in one fisheries system—the coastal zone. As a resource management approach, integrated coastal resource management addresses the goals of sustainable development by seeking to maintain the functional integrity of the resource system; reduce resource use conflict; maintain the health of the environment; and facilitate the progress of multisectoral development (Chua 1993). Burbridge (1994) stresses the need to maintain the functional integrity of coastal ecosystems, i.e., the hydrology, material flows, nutrient flows and energy. Wilson et al. (1994) also concluded that sustainable fisheries appeared to require maintenance of all basic biological processes such as breeding, migration and feeding.

In recent years, efforts are being made to develop research tools such as coastal transects (Pauly and Lightfoot 1992), geographic information systems and system analytical models such as ECOPATH II (Christensen and Pauly 1993), bioclimatic and fisheries oceanographic modelling to study whole or parts of the systems. Concentration to date, however, has been predominantly on the biophysical. Some countries, chiefly in the developed world, are trying to operationalize multispecies and ecosystem management concepts in fisheries resource management (Standing Committee on Fisheries 1992; National Research Council 1994) and scientific research (e.g., the large marine ecosystem concept, Sherman, Alexander and Gold 1993).

The biophysical and socioeconomic interconnections between fisheries and other sectors have only recently received close attention. Therefore, it is too early to see specifically how systems analysis and systems thinking will improve the management of the resource and their ultimate contribution to sustainable food security. Systems thinking will help identify the gaps in fundamental knowledge which are key to better understanding and functioning of the whole

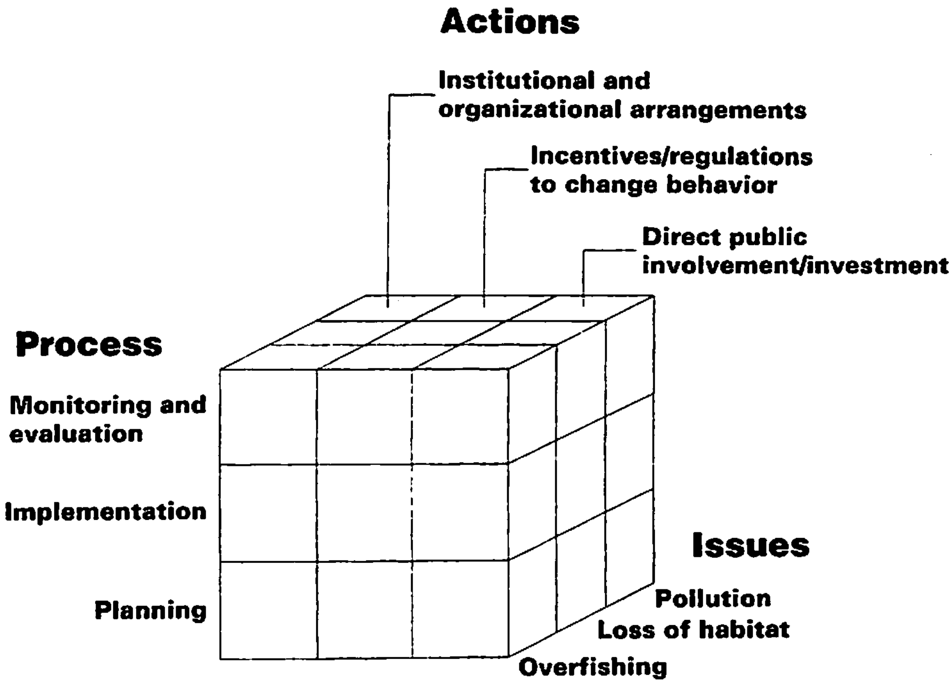


**Figure 13.** Integrated coastal zone management

system and hence can guide attention to those areas. Policy development, institutional linkages and communication across different government agencies, NGOs and researchers at local, national and international levels should help improve decision making.

### Nationalization vs internationalization

More than most other food commodities, tension between national and international interests arises over issues such as trade, local and international market competition for fish, demands for fisheries access by foreign fleets including vessels redeployed from overexploited fisheries in developed countries, illegal cross-border fishing and management of shared stocks.

Removing excess fishing capacity from overfished stocks is a major national issue. One of the most significant outcomes of the United Nations Convention on the Law of the Sea (UNCLOS) was the nationalization of fishing capacity, a process which is continuing today, e.g., in Indonesia (McBeth 1994). With the exception of such fisheries as the western Pacific tuna fishery, fishing within the exclusive economic zones is becoming increasingly the reserve of enhanced national fleets. Distant-water fishing nations are more restricted in access than ever before. At the same time, countries such as Japan have compensated by increasing their imports.

UNCLOS first provided some backing for extensive national ownership of aquatic resources. Akin to UNCLOS, the International Convention on Biological Diversity (ICBD) strengthens national rights and increases national responsibilities. It provides for national sovereignty over biological resources while recognizing there is a "common concern" for the conservation of biological diversity (Glowka and Burhenne-Guilmin 1994). Nations must link sustainable use and conservation, and they must protect and encourage customary use of biological resources. The experience of UNCLOS shows that many countries will have to strengthen greatly their capacity for biological resource management.

FAO (1993e) reviewed the impact of the first 10 years of UNCLOS on fisheries and concluded that the benefits were disappointing and could not be expected to improve until countries practised better domestic fisheries management.

The ICBD's influence on the use of living aquatic resources has yet to be tested. Access to and exchange of germplasm for improving aquaculture genetic resources will be an early issue. The ICBD should stimulate better documentation of aquatic biodiversity and interest in products such as Fishbase (Froese and Pauly 1994).

Trade is changing the patterns of consumption of fish. As with small-scale agriculture in the developing world, fisheries and aquaculture producers are often also significant consumers of their product. Prices of fish on world markets are increasing as supplies stagnate and the demand increases through population growth and rising incomes, particularly in the developed and newly industrializing countries. As prices of fish increase, more is being traded and relatively less consumed by the producer. In addition, price rises make access to resources more desirable. Small-scale and artisanal fishers are most likely to be marginalized under these conditions (Pauly 1994a), thus not sharing in the benefits of increased commodity prices and suffering nutritional and employment losses.

## The Contribution of Living Aquatic Resources to Food Security During the Transition

Sustainable food security is not achieved through any single, simple solution but needs (a) sufficient, stable, predictable and sustainable supply of food; (b) access to food; and (c) nutritional adequacy. Living aquatic resources can best help meet each of these needs particularly if countries go beyond fisheries and aquaculture to capture much greater, more enduring benefits from the use of the resources.

Greater scarcity of living aquatic resources in the near future should be used to stimulate desirable change in the way we manage and use them. The shock of the transition can help focus on some of the opportunities for their better use.

Postharvest handling should be improved; better use made of bycatch; alternative livelihoods sought for many fishers; alternate products and markets developed to maximize the value of production; the economic performance of fishing overhauled; new species tested and culture practices improved for aquaculture; small-scale aquaculture integrated into farming enterprises to diversify; some habitat protected for resource regeneration, ecotourism, etc.; and usage integrated into coastal and inland management regimes.

## Stable, sustainable, predictable supply

The contribution of living aquatic resources to food supply is deteriorating as the gap between supply and demand for living aquatic resources is growing. Supply is static at best but demand continues to grow. To prevent this situation from deteriorating further, the resource base for production of living aquatic resources must be kept in healthy, functioning order through protecting the regenerative potential of natural stocks; maintaining high-quality, high-diversity options for the genetic resource base for culture; and protecting the integrity of ecosystem functions in production systems, natural and artificial. Healthy aquatic ecosystems mean improving environmental practices on adjacent land and in watersheds.

Aquaculture production must be greatly increased through a strong injection of research and development.

Good resource management may be achieved with social cooperation, sound environmental stewardship, appropriate technological knowledge and development for production, economic rationalism in production and good postharvest handling.

To predict the level of sustainable fish supply, we require much better knowledge of the fisheries resource base, the dynamics of aquatic ecosystems, the impacts of climate and the effects of habitat degradation and pollution. This knowledge will take a large coordinated effort but there are multiple benefits and a start should be made now. Better resource predictability will greatly improve resource managers' capacity to manage and fishers' capacity to target catching more efficiently.

None of the above can be achieved without concerted national and international management action and an increased investment in scientific research to provide the know-how. Planning should have started years ago for key resource systems. The urgency increases over time as aquatic conditions deteriorate. Particular attention should be given to those areas in the developing world which are most dependent upon living aquatic resources. Should these suffer the types of collapses seen in the Grand Banks cod fishery, the consequences will be catastrophic, as few governments will be able to afford the type of assistance given by the Canadian government.

## Access to food

Food security requires access to the means of food production and/or to purchasing power through adequate income. Despite increasing scarcity of supply, better economic use of living aquatic resources could greatly improve the purchasing power of low-income users, provided they retain access to the resources as values are improved. Access rights will govern an individual's or community's rights to use living aquatic resources in the best way to achieve sustainable food security. Their allocation will have to satisfy multiple criteria such as equity, resource sustainability and economic efficiency, in an optimal way.

Governments should recognize that allocating access rights is more difficult as the world's fisheries resources diminish and more people wish to use them. We should be planning more adjustment studies, alternate livelihoods for fishers and development projects in anticipation of increasing scarcity.

Small-scale fishers should be empowered by giving them a greater level of organization, a greater say in the way the resources are managed, greater access to training to improve their skills, and alternative full- or part-time livelihoods. The role of women in fisheries enterprises should be recognized and given greater prominence, especially as they could have an immediate impact on supply by improving postharvest quality. Women should be given greater access to capital for small-scale postharvest operations and in aquaculture.

For the low-income urban and rural fish consumer, price will also determine access to the resource as food. Minimizing the supply-demand gap, and improving the economic efficiency of production will assist both the producer to get a fair price and the consumer pay a fair price. These factors will be countered and often outweighed, however, by actions to improve the value of products. On balance, the price of fish is likely to keep rising.

Countries should encourage new entrants into small-scale, low-input aquaculture, integrated aquaculture-agriculture, and appropriate intensive aquaculture so as to improve fish supplies and the many other environmental services provided by on-farm ponds and fish. Large policy and research investments are required now to help realize the full benefits of these technologies without causing environmental damage.

## Adequate nutrition

Nutrition is threatened in low-income households during the transition period. In developing countries where aquatic products are currently important dietary items, the supply and disposition of product is a particularly critical issue. Nutrition studies and health education programmes should be targeted now to ensure that diminished household fish supplies, as a result of lower production or through market sales as prices rise, are substituted by other nutritious foods.

Increasing scarcity of supplies versus demand should be used to stimulate greater efforts in postharvest quality control and thus provide a sounder base for future handling.

## Looking to 2020 and Beyond

The transition in living aquatic resources and their use raises questions as to what the future might look like in 25 years time—the year 2020. The following is a first attempt at such a projection.

### Production

In 2020, production will rely less on natural stocks and more on aquaculture and enhanced stocks, but not to the extent where the majority come from culture. A further 25 years at least will be required to achieve that. The challenge is to maintain present or near-present levels of natural harvest while sustainably increasing aquaculture production.

A detailed assessment of likely global production is not attempted here though would merit a serious modelling effort based on assumptions about trajectories of various natural resources, the likely gains from aquaculture and the tradeoffs in resource use. A landmark assessment for natural stocks was conducted 25 years ago by Gulland and others (Gulland 1970). ICLARM's 1992 Strategic Plan looked at potential increases in world fish catch in all regions and estimated a potential increase of 25,700 t was possible under ideal conditions of management to produce maximum yields and with full conservation of critical habitats including coral reefs. No parallel assessments have been attempted for aquaculture.

At best, all present indications are that production by capture fisheries will be only at about their present level in 2020. Qualitatively, gains from better handling of catch, more use of bycatch and the exploitation of the few remaining underutilized stocks will likely be at least offset by losses from poor management, protection of areas and species from fishing, and decreased carrying capacity of the environment through continuing environmental degradation. The biggest unknowns are in the apparently cyclic rise and fall of some of the largest fisheries stocks due partly to ocean climate factors (e.g., El Niño events and other large-scale patterns); in which existing fisheries will collapse; and in whether some presently collapsed stocks will recover and to what extent. Fisheries collapse may be sudden as in the case of the Peruvian anchoveta and the Grand Banks cod stocks, or more gradual. Tropical multispecies, demersal fisheries have not shown the same propensity for sudden precipitous collapse as some of the large temperate fisheries and fisheries for small pelagics. Under heavy fishing pressure, they decline gradually though surely, their species composition changing to favour smaller species lower on the trophic scale. The endpoint is gradually depleted stocks of less desirable species.

Asian countries will continue to dominate world fisheries but only if they can control their major environmental problems and better manage their fisheries within the next 25 years. Asian artisanal and subsistence fishers will be fewer in number but will be given greater control of inshore and coral reef fisheries in some countries. In others, the small-scale commercial sector will dominate, using modern gear and with its activities tightly controlled. Latin American fisheries will become more commercialized. African fisheries will be sporadic in their development, depending on the political stability of national governments, the pressures from foreign fleets and the resilience of stocks. Greater coastal fisheries development will occur but will be hampered by growing coastal pollution and habitat destruction. The great lakes fisheries will be subject to continuing large changes in species composition and likely greater efforts to privatize the control of resources.

By 2020, world aquaculture production will increase, but not at the rate needed to maintain the present per capita supply of aquatic products to a growing world population. Production will increase sporadically through the introduction of new areas, species and practices, and by increased production from existing systems. In both inland and marine waters, however, other agricultural, industrial and urban activities will compete strongly for good quality water, space and other inputs such as feed, fertilizers, labour and capital.

Major setbacks will be caused from time to time by disease outbreaks, pollution and poor management practices. These can be prevented or overcome through interventions such as research and development, extension, monitoring, legislation and good quarantine practices.

An urgent injection of research and development is required now to produce new technologies, strains of culture species, domesticate new species and to prevent environmental and disease setbacks. The rate of progress will depend on developments in the research pipeline and the time to produce new results and, through good early partnerships with farmers and industry, to transfer these into viable practice. For example, genetic improvements in fast-growing species such as tilapias still take at least five years to produce and some years to disseminate safely onto farms. Longer-lived species will take much longer. Between 5 and 20 years are needed to domesticate new species and bring them to market, depending on technical and socioeconomic factors.

In the developing world, Asia and Latin America will make greater progress than Africa in aquaculture. Sub-Saharan Africa will remain the least developed for some time to come, and the major and most appropriate mode of uptake will likely be small-scale aquaculture integrated with mixed agriculture. Major development, sensitive to the socioeconomic and cultural settings for the agriculture sector, is required to increase the practice of aquaculture in Africa. Climate and climate variability will be critical also as many of the enterprises will rely on rainfed ponds or relatively abundant irrigation water. Low-input integrated aquaculture-agriculture offers promise of sound and sustainable resource management but requires a greater level of knowledge than traditional agricultural practices.

Some countries in the developed world are favouring intensive, high capital, high technology offshore systems or onshore closed systems, including complete recycling linked to other industries, e.g., the brewing and waste management industries. These are being designed to overcome negative environmental side effects of aquaculture as well as to provide positive ways of solving the environmental problems of the other industries. The costs of inputs are often high, and profitability will depend on high market prices for products.

In 5 to 15 years time, many of the major high-level carnivores cultured will be fed on diets free or almost free of fishmeal, as nutrition research develops digestible alternatives providing the correct balance of amino acids and other dietary essentials. These alternate feeds will not remove all problems of feed supply, however, but will at least remove the dependence on other fish.

In 2020, genetic improvement, and probably genetic engineering of aquatic organisms, will be well advanced and will have provided some new strains of species suited to common culture conditions and with desirable growth and market characteristics.

## The biological resource base

Harvest fisheries and other human impacts will continue to degrade the diversity and abundance of the biological resource. This will have a negative impact not only on harvest fisheries production but also on the raw material for culture. In culture systems, more production will come from fewer species as the knowledge of how to culture the main species grows. However, some new species will be brought into production and a wider range of strains of existing culture species will be developed.

Caution on the safety of introductions and the national sovereignty provisions of the International Convention on Biological Diversity will slow the exchange of aquatic germplasm at least until the turn of the century, by which time suitable arrangements should have been negotiated to free up access more safely and equitably.

More conservation areas will be declared than at present but their extent will still be below critical levels to protect major species, biological and ecological functions, and habitat diversity. We will still know too little to design adequate between-systems of protected areas for conservation.

## The geography of production and consumption

The developing world will continue to lose out to the developed world in fish consumption. The total developing world production will not continue to grow at its present rate as more harvest fisheries become overexploited. Exports will continue to rise from the developing to the developed world, and as developing world population burgeons, fish will become even more scarce to the low-income consumers of the developing world.

Suitable climate, water, space, capital, labour and know-how will dictate which parts of the world produce most by aquaculture. China's contribution could plateau over the next few years. Bangladesh, Vietnam, India, Thailand, the Philippines, Indonesia and several Latin American countries will make big gains by virtue of their agroecological endowments. The Pacific Island countries and other island countries and areas in the Caribbean, Indian Ocean and Middle East will make great strides in culturing high-value invertebrate products such as giant clams, sea cucumbers, pearl oysters and trochus. These products will be used and consumed in the developed world.

## Economics of world fisheries

By 2020, greater economic rationality will prevail in the world's capture fisheries, but the interim 25 years will be marked by many conflicts on the road to rationalization. The economics of inputs (vessels, gear and operating costs including postharvest costs) will be better planned than at present. In aquaculture, much attention will go to driving down the costs of inputs and increasing efficiency.

Fish is unlikely to ever return to being the "poor man's protein". The prices of aquatic products will remain high, thus maintaining economic incentives to exploit natural stocks, driving competition for access and rights and the development of aquaculture. In aquaculture, the high price of products will continue to cause conflicts between aquaculture and alternate land uses, especially agriculture. Coastal shrimp ponds are being constructed on former coastal rice lands throughout humid Asian regions. Aquaculture will also compete for space and fresh and salt water. Because of the high price of fish and the high capital needs of some intensive enterprises, aquaculture will be controlled by large investors and will outcompete other land uses. In the Philippines, shrimp ponds have recently been exempted from the major agricultural land reform programme which seeks to transfer land to small producers.

Higher value, including nonfood, uses of species will diversify the markets and add further value to many fisheries and aquaculture activities.

## Supply, demand and world trade

Aquatic products will continue to be very highly traded. Producers in the developing world will eat less of their own product, whether they harvest natural or cultured stocks. The processing chain will become more important and internationalized due to the often conflicting demands for keeping costs down, creating employment, and maintaining quality, sanitary and health standards.

Trade liberalization under GATT will also generate trade wars and alternate forms of trade protection such as those based on environmental and human rights concerns.

Supply will be increasingly controlled by commercial, market interests through private aquaculture ventures and controlled marketing of fish. Governments and fishers' cooperatives will have diminishing roles.

## The people in fisheries and aquaculture

The next 25 years will see a large shift in the way people participate in the production of living aquatic resources. For the artisanal and small-scale sectors, and for rural people who relied on fish as a low-priced source of protein and other nutrients, the changes will be profound and may be largely negative. Deliberate interventions will be required to obviate the worst consequences of dispossession and nutritional shortfall.

Many fewer people will be dependent on harvest fisheries. Many will leave through natural attrition, depletion of resources and loss of access which will be limited and more controlled. Those who remain will be more empowered to control the use of the resources. New models of private appropriation will apply to many resources. Comanagement models involving community-based management will succeed in some cases (Pomeroy and Williams 1995). Commercial fishers often will cede access to small-scale artisanal fishers as the social, political or resource situation dictates. In others, fewer commercial fishers operating more efficient gear will dominate.

Many more people will participate in aquaculture though often employed on capital-intensive ventures. Small-scale farmers in Africa and Asia will participate part time. Technical extension programmes will be more widespread than at present but will often be provided by NGOs or the private sector. In developing countries, the private sector will be more developed in terms of hatcheries, buyers, equipment and other input supplies in much the same way that the agricultural sector is now advancing in these countries.

## The environment and climate

Climate is one of the greatest unknowns in capture fisheries, since even small shifts can have critical effects on species composition and abundance of natural aquatic populations. Some species and regions will be winners whereas others will be losers. For example, a recent study showed that a mean shoreline temperature increase of about 0.75°C between the 1930s and the 1990s at one site in California advantaged the fauna from warmer climates (Barry et al. 1995). Climate and climate change will also influence aquaculture but here, just as with agriculture, some measure of adjustment and control over production is possible, especially as climate prediction is improving rapidly.

In inland aquaculture, much greater attention should be paid to incorporating climate factors into production systems. Farm ponds themselves can act as buffers against drought through producing fish and providing water for other farm activities such as cultivating vegetables and other crops.

Over the next 25 years, the aquatic environment will be increasingly impacted by terrestrial activities and habitat alteration and climate change.

Fresh water will become a critical issue for all countries and peoples. The quantity, quality and disposition of fresh water will be increasingly altered by direct use, pollution, construction of dams, draining of wetlands, irrigation, salinization and biodegradation through eutrophication, harmful blooms of algae and introductions of alien species. Some developed countries have shown that many forms of pollution can be controlled with sufficient industrial and political will and incentives. Will the developed world take the even stronger action needed to halt degradation and will other countries such as the newly industrializing countries of Asia, Latin America and Africa take measures before too much damage is done?

Marine, especially coastal, water is increasingly impacted by human activities and this is likely to increase, especially from nonpoint sources such as sedimentation from land clearing. The changes wrought will probably diminish the carrying capacity for natural stocks of fish.

Rehabilitation of aquatic systems will receive greater attention over the next 25 years as people realize that unwanted changes have diminished their environment. At first, technologies from the developed world will be applied for remediation but gradually new and more appropriate ones will be developed.

### Postharvest

Markets will dictate products such as convenience foods (e.g., frozen fish, surimi products) and novelty products such as rare species. The former will be more generic and not specific to seafood lines whereas the latter will emphasize aquatic origins. Greater use will be made of byproducts (skin, bones, fine oils, shells) and bycatch or incidental species. Research investments are required to realize these uses.

The obvious limitations in supply of aquatic products will place greater emphasis on better utilization.

## How can research contribute?

The changes in the status of aquatic resources, the transition facing their users and the outlook present great challenges and opportunities for resource management research. The outlook affects how we choose, perform and deliver research, and the time frames for its conduct. This final section describes the roles and history of recent aquatic resource research as an entry to developing the most appropriate role for research.

Williams (1992) described how agricultural (including fisheries and forestry) science has to change to meet the challenges of present environmental and social demands, which are more complex than those of the "green revolution". The need for changes in research approach is pertinent to aquatic resource management research, although much of it is coming from a different starting point to traditional agricultural research. The nearest aquatic equivalent of the green revolution was the recent expansion and development phase of capture fisheries. Living aquatic resource research now needs to increase its emphasis on culture systems and broaden its use of environmental, climate and socioeconomic research. Agricultural research now must pay greater attention to the natural biological resource base, and greatly increase its emphasis on climate, the environment and socioeconomic dimensions.

Research directions must be informed by and help inform the strategic directions of the transformation in aquatic resource use. Research-based knowledge will be an essential but far-from-sufficient aid to developing countries, but only if it is strategic, purposeful and in touch with needs and the opportunities ahead.

Roussel, Saadand and Erickson (1991) defined "third generation R & D" as that which responds to existing needs and to the coming needs while contributing to the identification and exploitation of new opportunities and new solutions. This model of R & D is now the most appropriate model for research for living aquatic resources management. Its strategic and management context and operating principles (Table 5) closely match those required for national and international research for living aquatic resource management.

The strategic setting is the transition now occurring in world fisheries and aquaculture and the vision that improved use and better management of living aquatic resources are needed to enhance the contribution they make to sustainable food security.

Fisheries have large research needs relative to the available research resources, especially in the developing world. At this stage of the transition, the right mix and sequence of fisheries research therefore must be selected carefully to help speed management applications to beat further degradation of the resource base and to begin to rebuild fisheries. That fish stocks have declined and that some have collapsed despite scientific warnings show that scientific findings may not be applied in time to conserve the resources if the social, political and economic circumstances are ignored. Social science research, including policy research, could help managers and users understand how to implement more timely conservation actions.

At the same time, large investments in aquaculture research are required to spur development and to ensure the sustainability of new practices.

**Table 5.** Desirable characteristics of the management of natural resource management research

| | |
|---|---|
| *Management and Strategic Context* | holistic strategic framework—the vision for food security and the present transition in aquatic resource use |
| philosophy | partnership |
| organization | breaks the isolation of R & D |
| technology/R & D strategy | technology/R & D and natural resource management strategies are integrated |
| *Operating Principles* | combined R & D and resource management insights |
| funding | varies with donor/national/local sources depending on how benefits likely to be distributed |
| resource allocation | based on balance of priorities and the risk/reward of a successful research outcome |
| targeting | all R & D has defined, consistent natural resource management and scientific objectives |
| priority setting | according to costs/benefits and contribution to strategic objectives |
| measuring results | against natural resource management objectives and scientific expectations |
| evaluating progress | regularly and when external events and internal developments warrant |

(adapted from Figure 3.4, Roussel, Saadand and Erickson 1991)

## The role and history of aquatic resource research

To the present, research for aquatic resource management has been mainly resource biology and stock assessment, gear development, a small amount of economic and social research, and some aquaculture development research. These research inputs were sufficient when resources were underexploited, human populations lower, aquaculture industries small and nonintensive, and the environment in better shape. They no longer suffice.

There are many uses of research and it plays several different roles in helping natural resource management. The users of the research for living aquatic resource management include international and national politicians and policymakers, local resource managers, fishers, fish farmers and potential fish farmers, other workers in the sectors, consumers, traders and other researchers.

Research plays at least four roles in assisting natural resource management.

(1) It produces basic knowledge on which strategic and applied studies draw. Thus, fish taxonomy, the fundamentals of biodiversity research, economic market theory, trophic dynamics of ponds and the sociology of village systems may be relevant to fisheries management and aquaculture research. The main users of the results of basic research are other researchers and, depending on the topic, the general public.

(2) Research identifies issues and their implications. Thus, scientific studies may assess the status of an exploited stock; social science research may reveal problems in the distribution of benefits from the catch; marine biology may reveal the shift in species composition of an important marine ecosystem; environmental research may reveal unacceptable pollution levels in waters used for aquaculture. The main users of this research are policymakers, fisheries managers, fishers and fish farmers, and other researchers. The results of this research should be conveyed in a way which explains clearly their meaning and consequences. Researchers should have a holistic understanding of the situation and should understand that their findings will not always lead to action. Ehrlich and Dailey (1993) and Caldwell (1990) point out that a special mix of social conditions is required before science is acted upon.

(3) Research helps resolve conflict. Should this fishery be managed as a single stock or as separate substocks? What is the risk of stock collapse if catches are increased? How will limited entry affect coastal communities? Will larger mesh sizes protect the small fish? Research can help resolve these questions or concentrate the disagreements on issues where value judgments have to be made. Results from research into these questions must be delivered quickly and in a well-targeted form to help resolve the conflict. Users will be those involved in the conflict or their representatives on committees and negotiating parties.

(4) Research produces new solutions and options. Fisheries production has become more productive and efficient with the development of new gear, fishing grounds, vessels and postharvest technologies. Fisheries social science introduced the concepts of limited entry and individual transferable quotas to developed world fisheries management. Aquaculture production is now entering a period of technical development, including new selectively bred strains of species, new hatchery and husbandry technologies and new feeds. In the future, scientific studies will suggest new fisheries management policy instruments, forms of aquatic environment protection and remediation, and ways of integrating fish and other resource production systems. This role is used usually when no immediate conflict exists or after a period of conflict when the parties have entered into a phase of seeking settlement or options. Social scientists are gaining opportunities to study and recommend new processes in fisheries

management after all parties acknowledge the resource and economic issues, and management and communities sit down together to find new solutions (e.g., see Luna (in press) for a Philippines fisheries case). The users of this type of research are predominantly the fishers and farmers, but also the fisheries managers and other policymakers.

Will science be as successful in assisting sustainable fisheries management and aquaculture development as it has been in increasing fisheries production and recommending sustainable catch levels? The answer should be yes, provided all four roles are used, sufficient research is well targeted to needs through close interaction between researchers and the users of their work, and the appropriate mix of social and physical science applies.

The utility of research in fisheries resource management was recently debated in the scientific literature and at major international conferences. Ludwig, Hilborn and Walters (1993) argued that sustainable fisheries management is unattainable, as demonstrated by many failures to prevent overuse. They challenged the prospects for achieving scientific consensus over sustainable levels of fisheries resource use and pointed out that even if achieved, scientific consensus advice was often not acted on, leading thus to overuse. They doubted that science and technology could provide answers to resource or conservation problems although adaptive management approaches were promoted.

In reply, Rosenberg et al. (1993) argued that sustainable resource use was a legitimate concept and although challenging, is soundly based in resource dynamics theory and achievable. They illustrated their arguments with examples of successes, and of failures. Many of the failures occurred despite scientific consensus. They described new developments in which science assesses risks in the face of uncertainty.

Ehrlich and Dailey (1993) described and supported the use of science in perceiving natural resource problems, understanding their mechanisms, and strategically assessing options for their solution.

Professional meetings of fisheries scientists are signalling the need for new approaches to resource management and science. The problems are remarkably similar throughout the world—threatened resource bases, too many dependent fishers and ineffective or failed management. The 1994 annual meeting of the American Fisheries Society discussed the need for a "paradigm shift" in fisheries science for management. The 1994 Annual Science Conference of the International Council for the Exploration of the Sea (established in 1902 among the North Atlantic nations) for the first time held extended sessions titled "Improving the Link between Fisheries Science and Management: Biological, Social and Economic Considerations". Several papers revealed the failures of management and sometimes science for management in significant fisheries such as those of the European Community and of Atlantic Canada.

Fisheries science has been dominated by biological sciences since it grew out of 19th-century marine biology (Cushing 1988; Pauly 1994b; Smith 1994). Much of fisheries science in this century has been devoted to assessments of fish stocks and their potential productivity. The greatest gains were achieved after World War II as fishing technology and mathematics combined to provide powerful field sampling and analytical tools with which to assess the stocks. Smith (1994) argued, however, that fisheries science adopted a too narrow approach, concentrating mainly on the fish stocks and paying too little attention to ecology and economics.

Knowledge of the biophysical environment of world fisheries is still in its infancy. Direct observation and measurement of stocks is hampered by the aquatic environment which also tends to produce a greater degree of unpredictability in the abundance and distribution of the resources (Gulland 1986). Some speculate whether the systems are chaotic or complex, in either case causing problems of predictability (Wilson et al. 1994). In addition, oceanographic (biological, chemical and physical) and climate knowledge is only now approaching a degree of utility for fisheries science, thanks to the many internationally coordinated research programmes of the last two decades.

Fisheries science developed to serve the longest-established industrial-scale fisheries such as those in the North Atlantic Ocean exploited continuously over centuries by European and North American fleets. We know that these fisheries are based on resources which are far less diverse than those exploited in most of the (tropical) developing world. More importantly, tropical and developing-country resources almost universally lack the long history of data required by most advanced fishery assessments. In recognition of the huge challenges facing tropical fisheries stock assessments, ICLARM developed a strategic research programme in tropical fish stock assessment. This programme has been continuous since 1979 and has had a strong impact on method development, software development and training throughout the developing and developed world (see *ICLARM 1993 Annual Report* for a summary).

Assessments are often thwarted by lack of good data. Many fish stocks have come from a stage of early development to overexploitation before sufficient information could be collected for sustainable management. Fisheries data are difficult and expensive to collect, especially for artisanal and small-scale fisheries, so that even with proper commitment, most countries face an enormous task in building up even the most rudimentary database for hundreds of species captured by many different means, in rapidly developing fisheries responding to increasing demands from growing populations and markets. The data collections must also tap traditional fishers' knowledge.

In many cases all over the world, scientific advice on safe exploitation levels is not implemented adequately because countries lack political will and effective management policy instruments, and because social and economic factors intervene. In other cases, the resilience of different stocks to exploitation is only available with considerable time series of biological and fisheries data over various states of stock abundance, although taxonomic group and life history may give a starting approximation (Mace and Sissenwine 1993). Indeed, biological science is only now converging on a consensus as to what constitutes a key biological reference point for sustainable fisheries resources, namely a level of spawning which will prevent recruitment decline over time (Sissenwine and Shepherd 1987; FAO 1993f; Myers and Barrowman 1994).

At the same time, there is considerable debate over the inadequacy of management on a stock-by-stock basis, the need for fisheries ecosystem management and the possibility of naturally induced decadal patterns of change in the composition of species assemblages. The impacts of climate and climate change on fisheries resources have received some attention and though likely to be profound, will require much more research to permit prediction (Parslow and Jernakoff 1992; Laevastu 1993).

Fisheries social science (economics and sociology) has developed much more recently than fisheries biological science and is only lately gaining attention in the developing world (see Charles et al. (1993) for a review). Fisheries anthropology has had a small but mainly descriptive place in fisheries social science. Since the challenges facing fisheries and aquaculture are social and economic as well as biological, these disciplines must receive greater prominence in future. ICLARM was one of the first organizations to include social sciences (economics, sociology and anthropology) in multidisciplinary research on fisheries systems through research in the Philippines (Smith and Pauly 1983); many others are now considering the needs for multidisciplinary work.

Policy research is also new but of key importance to assisting natural resource managers. Policy research contributions have had profound impacts on national governments in fields such as agriculture and are starting to have an impact in the developed world in fisheries and aquaculture. Policy research can both inform and study the process of policy development, in the latter case drawing lessons and permitting new models.

## Strategic research for living aquatic resource management

National and international research programmes for living aquatic resources need to be reshaped, recognizing the strategic context as outlined in this paper, i.e., the imperatives of the transition facing aquatic resource users. Agencies must also overcome the difficulty of raising research funds by considering costs and benefits, priorities, the likely contribution to strategic objectives for sustainable food security, and recognizing that research plays several different roles and has many different users.

As the world looks ahead to the gap between supply and demand of living aquatic resources, and contemplates the likelihood of reducing that gap, research must be increasingly anticipatory. Research programmes must embody elements of looking forward to the consequences of present actions or outcomes, guarding against negative impacts and protecting options, foreseeing and attempting to satisfy future demands, and timing itself to maximize its chances of being useful.

Garcia (1992) and Smith (1994) argued that throughout its history, fisheries research both benefited and suffered from its close linkages to fisheries management agendas, driven by present and short-term questions. These dictates have generated research opportunities, resources (which are necessarily large and expensive when work at sea is involved) and questions, but have caused frequent changes in research direction and prevented resolution of longer-term and fundamental problems such as the link between fish recruitment and spawner abundance. The same situation will inevitably be the way of the future, making living aquatic resource management research extremely challenging and making strategic research directions difficult to maintain.

Research agencies involved in living aquatic resource endeavours should consider two strategies when devising their future programmes. These are to break down the isolation of aquatic resource research and development, and to fully use the four roles of research. To enable these strategies, more resources in total will need to be devoted to aquatic resource research.

**Strategy 1: Break the isolation of research**

Living aquatic resource research needs to be constantly in touch with the systems within which its work will be used. Boundaries need to be crossed by collaboration between research centres where synergies in research are possible. Aquatic resource issues need to be linked with terrestrial resource issues to benefit total progress towards food security.

Aquatic resource research needs to be in touch with aquatic resource and other resource management systems (e.g., coastal zone, water) and with agriculture. Integrated systems thinking is already having impact on research methodology for aquatic resources.

National and international research systems need to be strengthened if they are to support national sovereign responsibilities for aquatic resource management. This will take concerted efforts in networking, training, regional cooperation and partnership research.

We need to break the isolation between researchers, between institutes and between research disciplines. Access to knowledge and research resources rather than ownership will be the way of the future. Networks of information and research collaboration will become more common. We must speed access to the latest scientific findings and methods between agencies, in South–South and North–South linkages. Fisheries and aquaculture research need to link with oceanography, hydrology, sedimentology, climate, marine biology, forestry, irrigation and general agricultural policy research.

Researchers are starting finally to break the isolation between themselves and the fishers and farmers for whom much of the research is targeted. Research agencies will work more often with NGOs which help fishers and farmers groups with the skills, social organization and capital wherewithal to benefit from new technologies. The principles of the early successes of participatory research and NGO involvement should be drawn out.

Biological research in fisheries and aquaculture is also integrating with other biological research at the molecular level, particularly in genetic identification of stocks and genetic diversity, aging of fish and studies of basic biological processes. Thus the Conway et al. (1994) treatment of the two new paradigms of agricultural research is also applicable to aquatic resource research.

**Strategy 2: Use the four roles of research**

Recognizing that research fulfils different roles—it generates knowledge, identifies issues and implications, helps resolve conflicts, and provides solutions and new options—provides the opportunity to develop and exploit its full potential to help food security. Sometimes researchers need to alert national and international agencies on management and policy issues for living aquatic resources and project the role research can play. At other times they will be reacting to needs identified by others.

If we have broken the isolation of research, researchers have a greater chance of getting their messages across, and of understanding the needs. They can therefore have a part in helping resolve a conflict, study the implications of a policy change, develop new ways to manage fisheries resources, or enhance farm productivity.

The present aquatic transition has received global attention for events in the developed world, e.g., the collapse of the Grand Banks cod fishery, but little for events in the developing world. Researchers now should be working to analyze, anticipate and highlight the transitional events and their likely impacts in the developing world.

**Required: More resources for aquatic research**

On balance, there are strong arguments to increase support for aquatic resource research as aquatic systems begin to suffer the changes and insults suffered by terrestrial production systems hundreds of years ago, but with less capacity to absorb them and more people relying on the food and other products they produce. As with signs of global change in the atmosphere and climate, we are now detecting global-scale signs of change in aquatic resources. The impacts on people will be immediate.

As with the recognition of aquatic resource issues, aquatic resource research has long struggled for attention against more visible priorities on the land. The resources, and therefore their research and management needs, have tended to be under water, out of sight and out of mind. This is less so now as aquatic environments and their biota begin to show the global impacts of terrestrial and atmospheric insults as well as of direct utilization.

There is no easy formula to help set aquatic resource research levels. Much aquatic resource research is more expensive than terrestrial equivalents, especially when it involves working at sea or with ponds and tanks. Most of the research is not amenable to economic cost–benefit analysis, which is most suited to research in its fourth role. A recent Australian study on fisheries research concluded that "evaluating alternate research projects . . . may be difficult because of inadequate information on many fisheries and sometimes the need to undertake a number of research projects to produce the desired output" (Lal, Holland and Collins 1994).

When allocating scarce research resources, many developing countries choose to place their emphasis on aquaculture technology research rather than on fisheries research (e.g., see Davy 1993), probably since the impact of the former usually is clearer. This allocation is despite the majority of production still coming from harvest fisheries about which too little is yet known. Fisheries and coastal resource management therefore lack adequate information for sustainable operation.

Factors which suggest a heightened emphasis on aquatic resource research in the developing world now are:

- the low level of present knowledge;
- the numbers of low-income people who depend on the resources;
- the urgent needs for viable policy options for better resource management;
- the increasing value of the resources and the impacts on the resource poor of the rising prices;
- the potential for aquaculture to make a large contribution but only provided it is environmentally sustainable; and
- the need to identify and intervene quickly to remediate the status of aquatic resources and their systems due to their position downstream of other systems (socially and environmentally).

Fisheries and aquaculture products alone represent the fifth-largest agricultural commodity. In large parts of the developing world, fisheries products are major contributors to food security, and this contribution is now the one most seriously threatened. Not only grain production but all sources of food, income and livelihood must be protected as populations increase.

It could be argued that returns from research are less certain in fisheries than in other fields. This, however, is a result of our present low level of knowledge of complex aquatic systems. Much of the existing knowledge has only been gained in recent decades and lags behind the knowledge base for most terrestrial systems. Aquatic resource management in ignorance is not a viable solution to food security.

## Conclusion

A dramatic and profound change is occurring in the living aquatic resource systems of the globe and this change will cause a transition for those who depend on and use the resources. Many people are alerted to the transition but little has been done to anticipate or obviate its consequences. The outlook is for a much-altered state of affairs compared to the present.

In the developing as well as the developed world, action must start now to achieve the best outcome for food security. Better aquatic systems protection and the best possible use of the living resources must be the target. Many interventions will be required. Of these, research can and must play a vital role, for indeed the best possible outcomes cannot be anticipated without an appropriate research investment now.

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