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Food, Agriculture, and the Environment Discussion Paper

The Transition in the Contribution of Living Aquatic Resources to Food Security

Meryl Williams

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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Food, Agriculture, and the Environment Discussion Paper 13

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Meryl Williams

International Food Policy Research Institute
1200 Seventeenth Street, N.W.
Washington, D.C. 20036-3006 U.S.A.
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Foreword

This is the thirteenth paper in the Food, Agriculture, and the Environment Discussion Paper series, a product of IFPRI's 2020 Vision initiative, which seeks to develop an international consensus on how to meet future world food needs while reducing poverty and protecting the environment. In this paper, Meryl Williams of the International Center for Living Aquatic Resources Management (ICLARM) examines the current state and likely future condition of the world's fish and other living aquatic resources as sources of food and suggests the role that research can play in helping develop sustainable management practices for the world's fisheries.

Although fish is often excluded from projections of future food supply, it is a very important source of food and it offers a livelihood for huge numbers of people, including many poor people, in developing countries. But overexploitation and other pressures on fish stocks in many of the world's natural fisheries could threaten food security in much of the developing world. Aquaculture—the farming of aquatic resources—is becoming increasingly important, but it must be intensified significantly and sustainably.

Compared with terrestrial resources, we know relatively little about aquatic resources and the systems within which they live. Research, improved knowledge, and better policies, therefore, can mean the difference between the destruction of many fisheries resources and improved management and use of these resources. In this paper, Meryl Williams shows how research can help aquatic resources make the greatest possible contribution to food security.

Per Pinstrup-Andersen
Director General, IFPRI

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

Aquatic products are rarely included in food supply calculations and are frequently overlooked in food security discussions at the national and global level (James 1994).[2] Cereals dominate most calculations of per capita supply and food security, but to assure future food security, all foods and economic activities, including production of aquatic products, will be needed.

This discussion paper addresses the outlook for living aquatic resources in food security and the role of research in improving that outlook for those to whom it matters most—low-income people in the developing world. It first discusses the global situation and outlook since research 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 paper reviews the reasons for this narrow role and describes an expanded and more effective role for research.

The Transition

Global fish supply is becoming increasingly scarce and more subject to human influences. The transition to relative scarcity cannot be prevented by more intensive fishing but rather will be ameliorated by better management of fisheries resources, improved aquaculture production, better use of resources, and interventions to improve equity. Human control of supply will need to be better understood and more wisely applied. 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 effects were negligible, technology had much

[1]Food security is defined as "physical and economic access, by all people at all times, to the basic food they need" (AGROVAC, FAO's thesaurus used for the International Information System for Agricultural Sciences and Technology [AGRIS]). Food security therefore embodies stable, sustainable, and predictable food supply; equity through access for all (through access to either the means of production 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."

[2]Of four major food supply studies reviewed by McCalla (1994), only Brown and Kane (1994) included fish and terrestrial animal products.

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 effects will be far reaching. The resources; the people who use and consume them; production practices; management institutions; the environment that supports them; and the local, national and international legal instruments governing their ownership and use will all be affected (Table 1). Without urgent anticipatory action, the world could forgo billions of dollars of income, lose tens of millions of tons of high-quality protein food, sacrifice millions of livelihoods, experience severe natural resource and environmental losses, and fail to exploit potential benefits. The cost of rehabilitation is escalating exponentially; in some cases the damage may become irreversible. 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, users and policymakers do not have sufficient know-how to extract the benefits immediately; in others, rapid interventions are required to reap the rewards.

The Present Situation in World Fisheries and Aquaculture

Aquatic resources are important food and economic resources for many countries. Valued at US$70 billion in 1991, aquatic resources make up 19 percent of total animal protein consumed and 4 percent of

Table 1—The transition in world fisheries and aquaculture

Affected Factor	Before 1990	After 1990
Resources		
Fisheries	At limits of sustainable production	Beyond limits of sustainable production, some stocks collapsed
Aquaculture	Expansion	Expansion continues
Uses	Food, feed	Increasing nonfood use
Society and economics		
Number of fishers	Increasing	Decreasing
Number of fish farmers	Increasing	Increasing
Resource conflicts	Starting, few solutions	Increasing, more solutions
Economics	Overcapitalization	Structural adjustments forced
Trade levels and prices	Increasing	Increasing
Production practices		
Fisheries	Restrictions	More restrictions
Aquaculture	Technology application begins	Increasing technology
Environment and climate		
Effects on fisheries and aquaculture	Increasing	Increasing to severe; aquaculture assists sustainability
International arrangements	United Nations Convention on the Law of the Sea (UNCLOS)	• United Nations Conference on the Environment and Development—Agenda 21 • International Convention on Biological Diversity • General Agreement on Tariffs and Trade • United Nations Conference on Population and Development • UNCLOS plus UN agreement on the management of highly migratory species and straddling stocks

total protein consumed (FAO 1992a). About 1 billion people rely on fish as their primary source of animal protein. Production of fish products far outweighs that of any one of the four terrestrial animal commodity groups (beef and veal, sheep meat, pig meat, and poultry meat). In developing countries fish production of approximately 60 million metric tons[3] approaches the total production of all four animal commodities (approximately 70 million tons). The International Center for Living Aquatic Resources Management has estimated that about 50 million people are involved in small-scale fisheries through catching, processing, and marketing (ICLARM 1992), and fish production provides some 150 million people overall with employment. Aquatic resources also provide important, though little recognized, environmental and cultural values and services now and for future generations, such as totem species, personal ornamentation, and symbols of seasonal changes.

Recently the media and many multilateral agencies have highlighted the crisis in the state of the world's fisheries, brought to public attention by concerns expressed by the Food and Agriculture Organization of the United Nations (FAO) and the World Bank, growing attention from major conservation groups, specific cases of collapsing fisheries in the developed world (such as the cod fisheries of the Grand Banks), and international fights over stocks between the fishers of various countries (FAO 1992b, 1992c; Garcia and Newton 1994; World fisheries 1994; Weber 1994a, 1994b; World Resources Institute 1994).

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 stocks that are shared by more than one country or that straddle the waters of one country and the high seas. This initiative was finalized in 1995. In the second initiative, the FAO is coordinating the drafting 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 United Nations Conference on Environment and Development (UNCED) Agenda 21 (FAO 1993a).

The third initiative is the 1993 International Convention on Biological Diversity (ICBD), led by national conservation policymakers and coordinated by the United Nations Environment Programme (UNEP). The ICBD has had little effect on fisheries and aquaculture management and conservation so far but has the potential to become the most influential instrument yet on fisheries, aquaculture, agriculture, forestry, and all human uses of life forms.[4]

A fourth international arrangement, the General Agreement on Tariffs and Trade (GATT), 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 on fisheries and aquaculture through the replacement of quotas with tariffs that will fall over time, through the opening up of some previously protected markets, and perhaps through environmental provisions. The agreement downplayed environmental and natural resource issues, however, in favor of rules against undesirable trade protection (see The cost of clean living 1994).

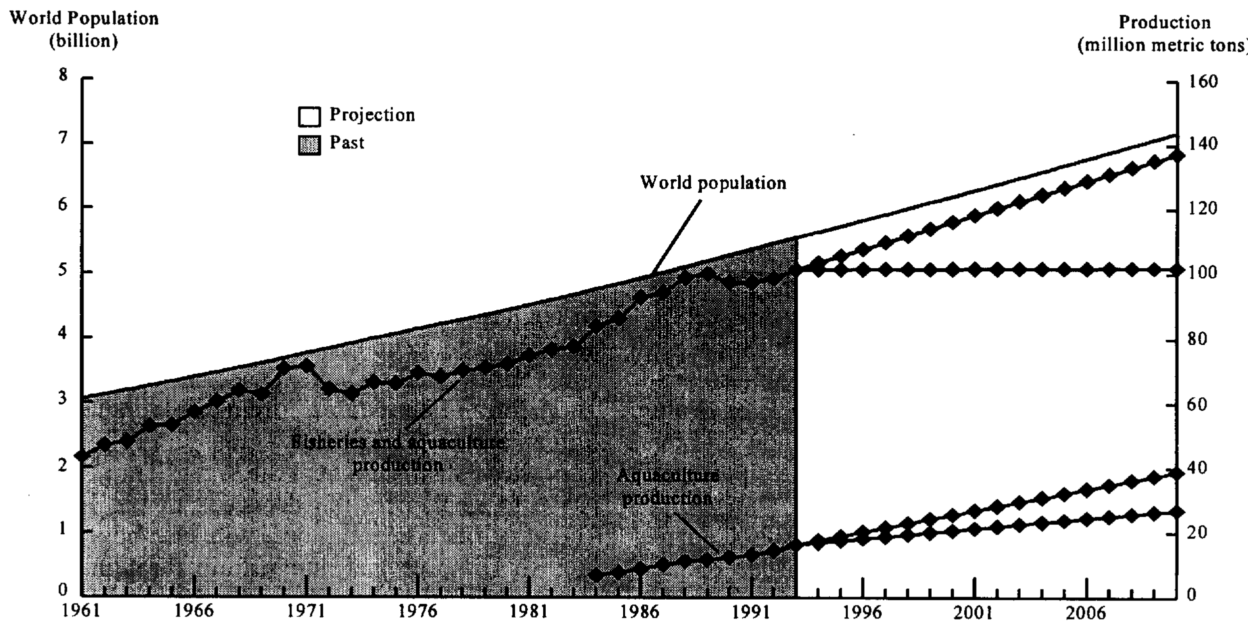
The fifth initiative is the UN Conference on Population and Development held in Cairo in September 1994 by the UN Population Fund. Its outcome should help achieve an eventual balance among resources, development, and population, but it does not obviate the effect of high per capita consumption of resources—the other part of the equation when balancing people and resources. Human populations will not fall fast enough to relieve the immediate pressures on aquatic products.

Another initiative that has stimulated activity in fisheries research and information is the multidonor study/strategy on international fisheries research

[3]All tons in this paper are metric tons.

[4]The ICBD 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 ICBD 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 ICBD then points out that to fulfill legal obligations, parties will have to in fact conserve and manage biological resources and ecosystems. Therefore, the ICBD contains the legal powers to govern all uses of life, including agriculture, fisheries, aquaculture, and forestry. It addressed agriculture first, because of that sector's long and well-documented use and transformation of plant and animal genetic materials. Fisheries and aquaculture uses and effects on biodiversity are less well known and thus aquatic biodiversity issues generally have received little attention.

Figure 1—World population and fisheries and aquaculture production, 1961–93 with upper and lower projections to 2010



Source: FAO 1993c and FAO 1995.
Note: Projections are based on a major expansion in aquaculture (to 39 million metric tons) and a reversal in the decline of capture fisheries through good management and better use.

(World Bank et al. 1993; Strategy on international fisheries research 1994).

Production. Production of fish by capture fisheries (total production minus aquaculture) reached its upper limit in 1989 (about 89 million tons) and declined to 85 million tons in 1993 (Figure 1). The expansionary phase of the 1960s, 1970s, and 1980s is over. For decades, if not centuries, humans have attempted to forecast the capacity of the oceans to feed the world (see, for example, Gulland 1970 and Idyll 1978). For the majority of natural fisheries resources,[5] these limits have been discovered through a combination of scientific research and monitoring and some practical if unintended experiments involving the fishing of stocks to or beyond their limits. The FAO predictions of Gulland (1970) appear to have been right in aggregate (about 100 million tons of sustainable annual production), though sometimes wrong in detail.[6] Now the upper biological limit is falling for many species as overexploitation erodes the resource base. In addition, for most fisheries the economic returns on operational costs and investments are negative, indicating that the economic values are totally depleted.

In 1993 estimates, world production was 84.3 million tons of marine products (93 percent from capture fisheries) and 17.2 million tons of inland aquatic products (38 percent from capture fisheries). Thus, global dependence on production from natural fisheries resources was about 83 percent in 1993, down from 89 percent when global production peaked at 100.3 million tons in 1989.

[5]The term "fisheries resources" encompasses those living aquatic resources taken for human use. In addition to fish (teleosts and elasmobranchs), they include invertebrates (echinoderms, crustaceans, and mollusks) and plants such as micro- and macroalgae. The plants are usually reported separately in statistics, although their harvest and culture, particularly in Asia, are important, and they serve many food and other product uses. Unless specifically mentioned, aquatic plants are not included in the statistics quoted in this paper. In 1992, 6.1 million tons of aquatic plants were harvested, 5.4 million tons of which were cultured.

[6]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 tons were predicted, but only about 200,000 tons were realized with development), because of extrapolations from regions with much higher primary productivity than that of the Australian fishing zone.

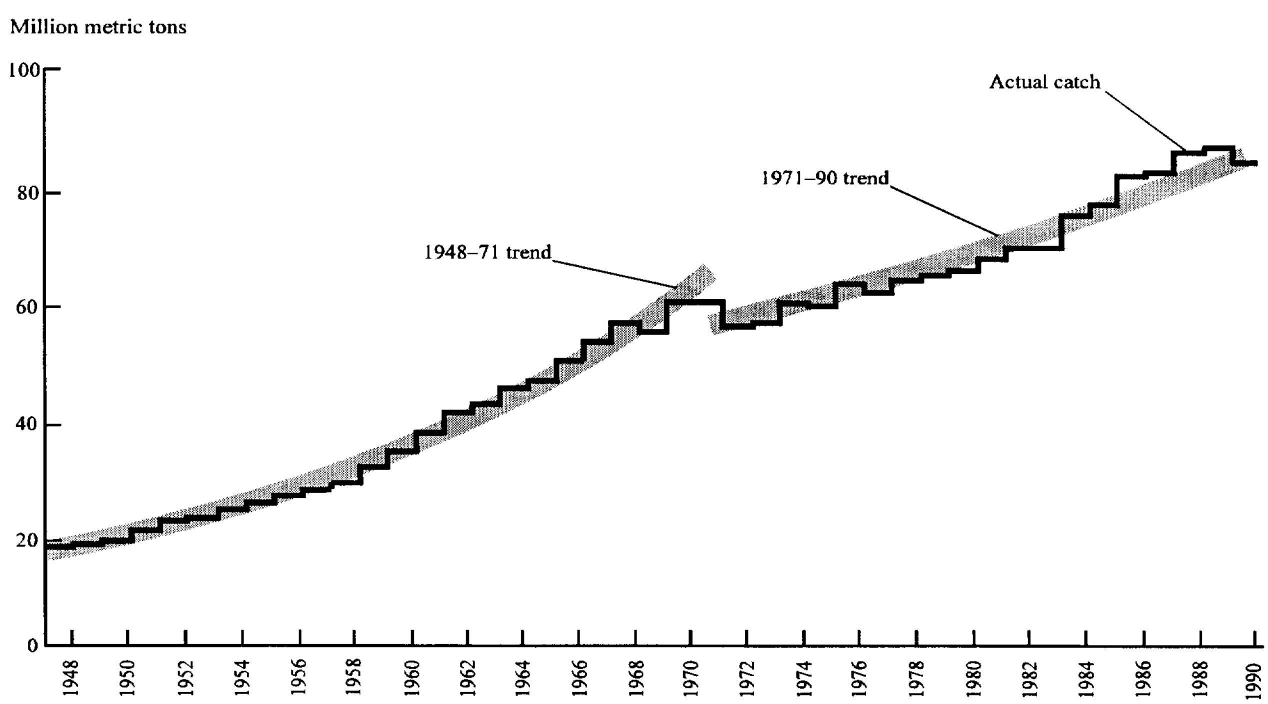
As populations continue to grow, especially in the developing world, and production from natural resources declines, the world is expecting aquaculture production to help bridge the supply-demand gap. World aquaculture production (marine and inland) more than doubled between 1984 (the first year with recorded global statistics) and 1993, reaching 16.3 million tons (FAO 1995). It is difficult to estimate potential global production because new technologies and new enterprises will certainly push the potential up, within the limits of the natural resource base and access to it. In contrast to natural fisheries production, production from aquaculture could greatly increase if care is taken in the expansion.

The downward trend for marine capture fisheries production is a cause for both national and international concern. 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 1971, annual marine fisheries production increased by 6 percent per year on average (Figure 2). After the collapse of the great Peruvian anchoveta fishery, however, annual production growth fell to only 2.3 percent in the 1970s and 1980s. Much of these smaller production increases over the last two decades reflects 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, such as demersal fish, lobsters, and sharks, have increased little over the last 20 years.

Production statistics give only a partial picture of production trends and potentials, which depend 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 more than a quarter are overexploited, depleted, or recovering and therefore would produce greater catches only if returned to a healthier state (Figure 3). Thirty-eight percent are fully exploited and therefore cannot produce more catch without depleting the base stock. Only a little more than a third could produce more (FAO 1992b).

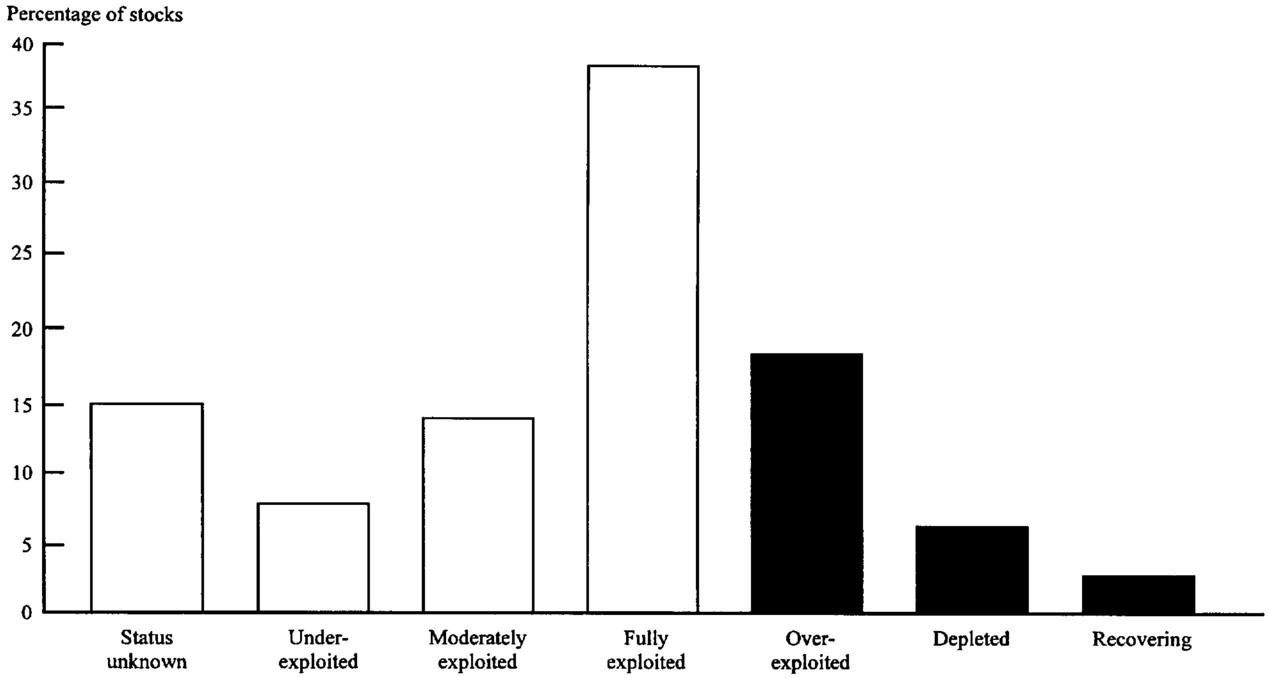
Despite the near doubling of the world population, the daily per capita supply of calories from fisheries and aquaculture has increased by more than 70 percent in developing and by about 50 percent in developed countries since 1961 (Figure 4). Average per capita consumption is already dropping, though

Figure 2—Growth in global marine catch, 1948–90



Source: FAO 1993e.

Figure 3—Status of the world's 200 main fish stocks, 1990



Source: FAO 1992b.

the leveling off started one year earlier in the developing world.

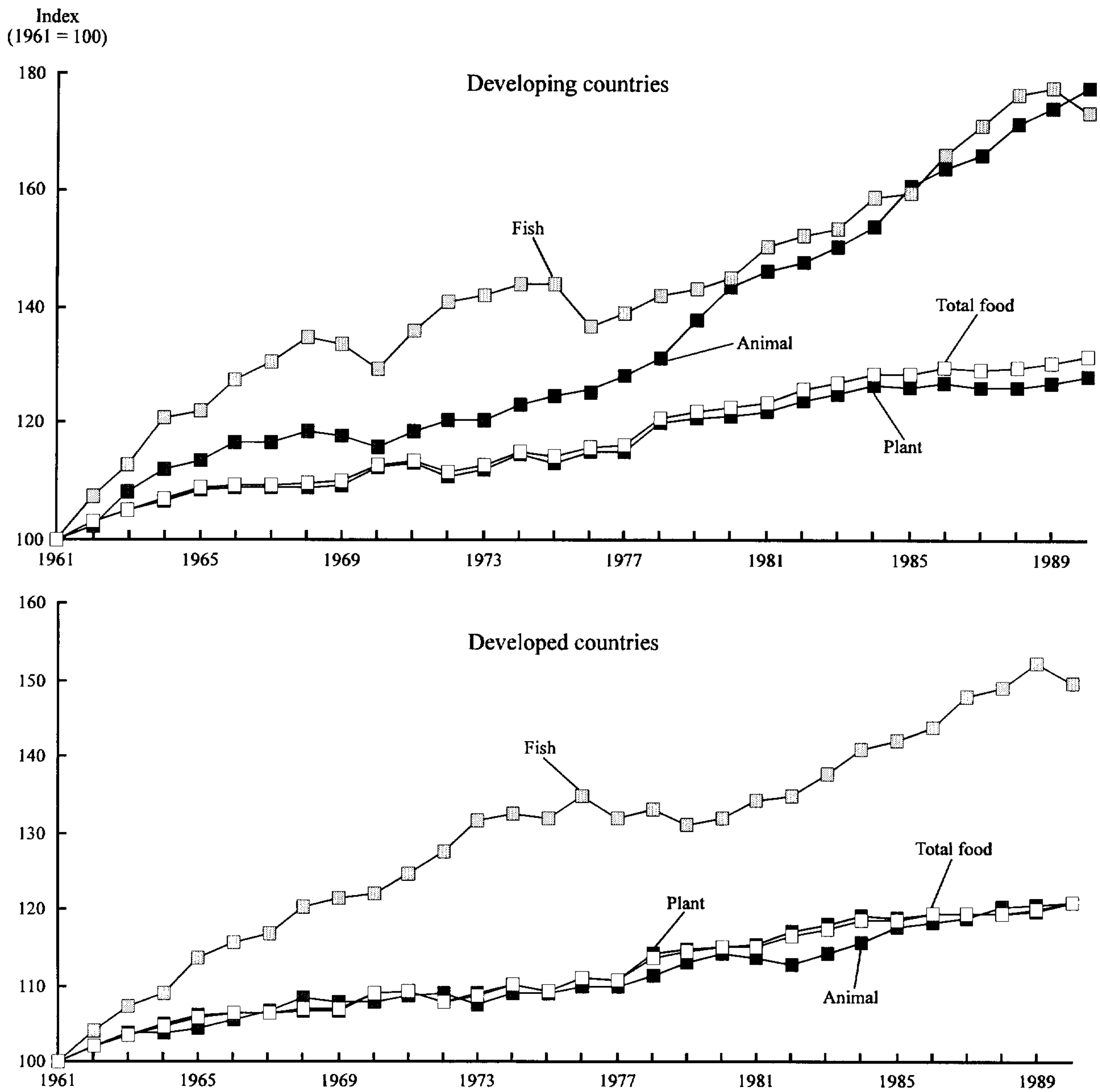
The Biological Resource Base. Capture fisheries are the largest users of natural biological resources today. In theory, as fishing reduces the abundance of a stock, compensatory growth produces a surplus (likened to the interest on the capital of the resource base) that can be sustainably harvested over time. In practice, estimating the capital base required to maintain the maximum interest or surplus production is difficult. Even if the base is 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 push for exploiting not just the surplus but also the resource base.

The complex composition of the resource base adds to the challenges of estimating sustainable production. High biodiversity at the genetic, species, and ecosystem levels is a key attribute of the living aquatic resource base. Humans use about 5,000 different species of fish and many hundreds of crustaceans, mollusks, and echinoderms directly (see Table 2 for numbers of fish) and rely on many more species indirectly through food and habitat support. The harvested species have varying biological characteristics that affect their seasonal and geographic distribution, abundance, and availability.

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

Fishing affects biodiversity, but its effects 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). The fishing out of 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

Figure 4—Daily per capita calorie consumption, 1961–90



Source: Data are from FAO 1993d.

affecting the degradation of coral reefs in all oceans; the other two are nutrient enrichment of reef waters from terrestrial runoff and sedimentation.

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; the possible greater resiliency of marine species to extinctions; and the fact 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 are native to their culture localities, but there are notable exceptions such as salmon, trout, tilapias, and carp, which have been widely

Table 2—Finfish used by humans

	Number of Species	Percentage of All Species
Extant finfish	24,618	100.0
Fish used in industrial and artisanal fisheries	2,576	10.5
Fish used in aquaculture[a]	179	0.7
Fish used as bait	134	0.5
Fish used in ornamental trade	1,980	8.0
Marine fish	546	
Freshwater fish	1,434	
Mainly artificially reared	773	
Fish used as sport fish	798	3.2
Total used by humans	4,572	18.6
Finfish affected by humans		
Threatened	770	3.1
Introduced[b]	221	0.9
Finfish affecting humans		
Dangerous[c]	437	1.8

Source: ICLARM FishBase as of January 9, 1994.
Notes: 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 fishes.
[a]Species used for food or stock enhancement in commercial aquaculture.
[b]Species transferred to and established in another country.
[c]Species that are, for example, poisonous or traumatogenic.

introduced to new localities. Although aquaculture has been practiced for more than 2,000 years in China, for example, and more than 1,000 years in Europe, until recently it has not been subject to the same intensive development of its genetic resource base and culture practices as terrestrial agriculture. For example, genetic improvement of fish is estimated to lag behind similar advances in terrestrial livestock by nearly 50 years (Eknath et al. 1991). Standard selective breeding techniques for enhanced production were begun for Atlantic salmon only in 1975 (Gjedrem, Gjerde, and Refstie 1988) and for tilapias by the International Center for Living Aquatic Resources Management (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 (see, for example, Eknath and Doyle 1990 on Indian major carps) or that the most common strains used may not always be the best performers (see Eknath et al. 1993 on Nile tilapia strains in the Philippines).

Table 3—Aquatic species used in aquaculture

Commodity Group	Number of Species Cultured	Number of Species of Higher Taxa That Account for More Than 95 Percent of Commodity Group
Seaweeds	6	4
Mollusks	43	9
Crustaceans	27	7
Finfish		
Freshwater and brackishwater fish	72	17
Marine fish	33	4
Total	181	41

Sources: Based on Pullin 1994. Original data and nomenclature from De Luca 1988, Taiwan Fisheries Bureau 1990, and FAO 1991.

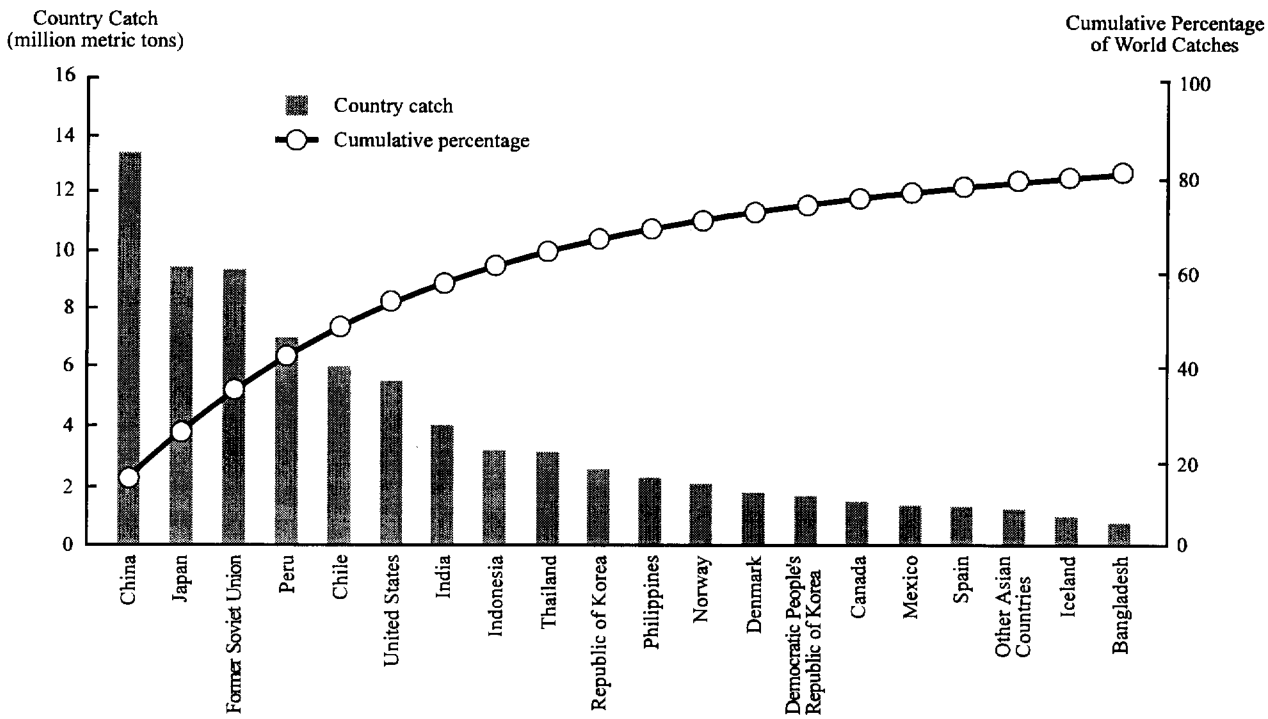
The distinctions between natural and cultured stocks are disappearing where cultured and natural stocks mix. There is, for example, biological competition between hatchery-reared and natural stocks in enhancement programs for capture fisheries (Hilborn and Winton 1993) and when farmed fish escape to the wild.

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) and herbivores (tilapias, milkfish, and some carp) to high-level carnivores and omnivores (shrimp, crabs, salmon, and trout). The trophic levels of many cultured aquatic species are much higher than those of their terrestrial equivalents except goats and pigs. Feed supply for higher-level predators is therefore important to the economics and efficiency of their production. Some cultured species depend on fish meal and fish oil in feed. Tacon (1994) estimates that the fish meal component of diets in aquaculture will eventually be reduced to about half.

The Geography of Production and Consumption. 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, the former Soviet Union, Peru, Chile, and the United States) produce more than half of the world's fish catch, and the top 20 countries produce more than 80 percent of the catch (Figure 5). In 1991, the former Soviet Union, Japan, and the United States took 3.2, 1.0 and

Figure 5—Total catches of top 20 countries, 1991



Source: FAO 1993d.

0.2 million tons, respectively, in nonadjacent waters (FAO 1993c). A breakdown of total production by continent shows the dominance of Asia in both marine and inland production (Figure 6). Total marine catches from the developing countries have exceeded those from the developed countries since the mid-1980s (Figure 7).

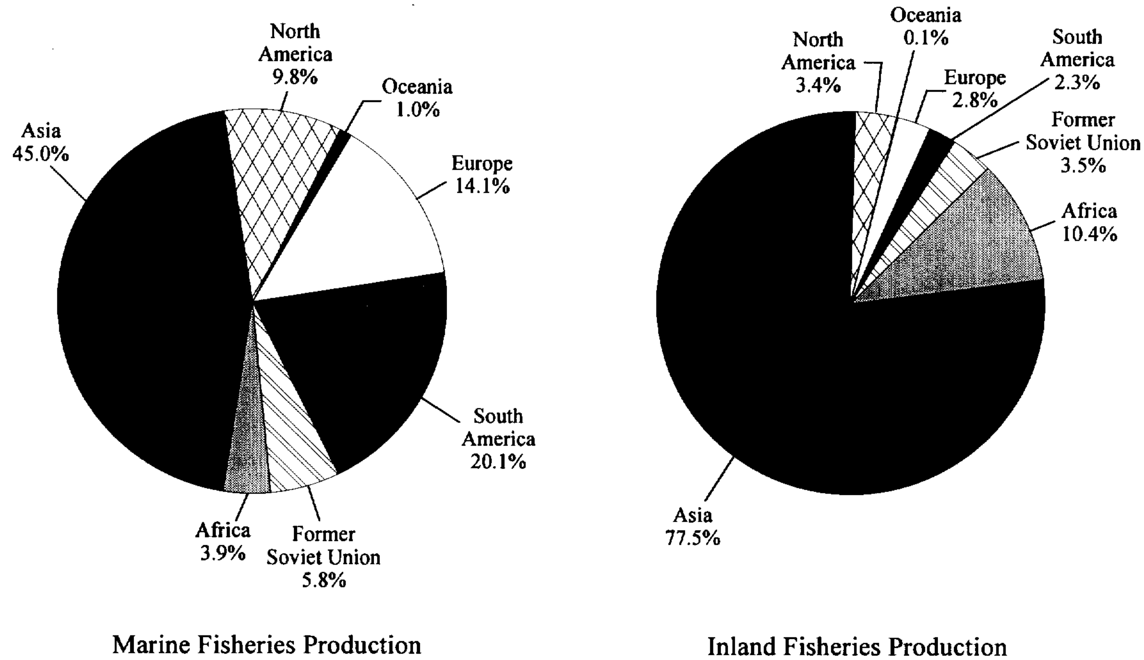
The production of complex organic substances such as amino acids, fats, and carbohydrates from simple inorganic forms of carbon, nitrogen, and oxygen compounds is known as primary production. The ecosystems in which the greatest primary production occurs are upwellings, coastal and coral reef systems, ponds, and lakes (Figures 8 and 9). Pauly and Christensen (1994) have calculated that 8 percent of aquatic primary production is captured in products for human use. In coastal upwellings, tropical and temperate shelves, and inland waters, 25–35 percent of primary production is taken up in the aquatic food webs leading to human use. (By comparison, Vitousek et al. 1986 calculated that for terrestrial ecosystems, 35–40 percent of total primary production was used by humans.)

Most of the very productive aquatic ecosystems occur close to continents or land; about 90 percent of capture fisheries production comes from coastal waters within the 200-nautical-mile 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. It is highest in maritime countries with greater access owing to greater supplies, greater purchasing power, or fewer alternative sources of animal protein. In the Maldives, Japan, and Iceland, daily per capita consumption is more than 200 calories, or nearly 10 percent of total food calories. Japan used 13 percent 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.

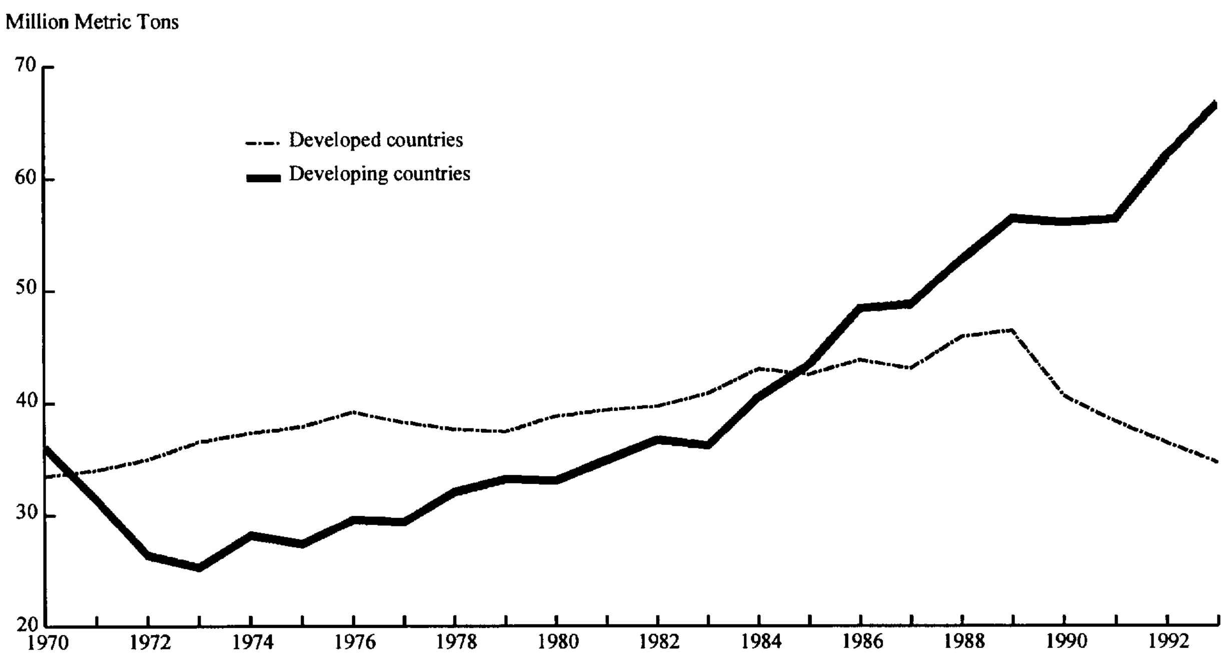
The Economics of World Fisheries. Though it is less well documented globally than the biological outlook, the economic situation of the world's fisheries stock is also poor (Garcia and Newton 1994). FAO (1992a) estimated that the world fishing fleet increased at twice the rate at which catches increased over the last 20 years. Even more serious, the fleet

Figure 6—Marine and inland fisheries production by continent, 1992



Source: FAO 1994.

Figure 7—Total marine catch by developed and developing countries, 1970–93

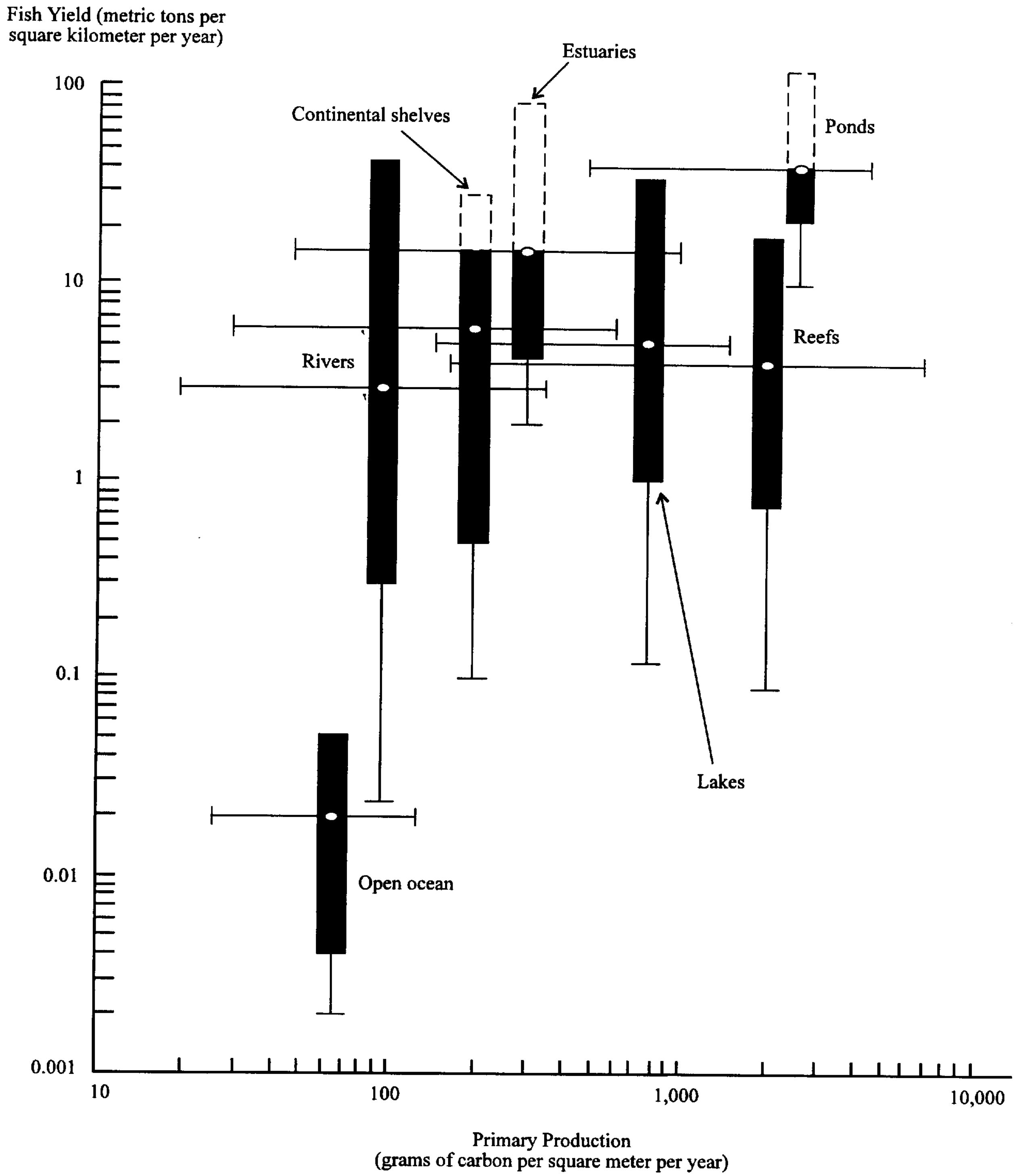


Source: FAO 1992b.

Figure 8—Upwelling areas and coral reefs

Source: International Center for Living Aquatic Resources Management (ICLARM).

Figure 9—Ranges of fish yields and primary production in various tropical ecosystems



Source: International Center for Living Aquatic Resources Management (ICLARM).

Note: Dots at the intersection of ranges represent modal values. Solid portions of the bars represent the range of maximum sustainable yields. Dashed projections at the top of the ranges for estuaries and ponds represent elevated yields from aquaculture with fertilization (but no supplemental feeding). The dashed projection for continental shelves represents higher yields that occur in areas of upwelling.

operates at an overall deficit of US$15 billion, excluding the return on capital from operational costs. This deficit 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 (Figure 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.

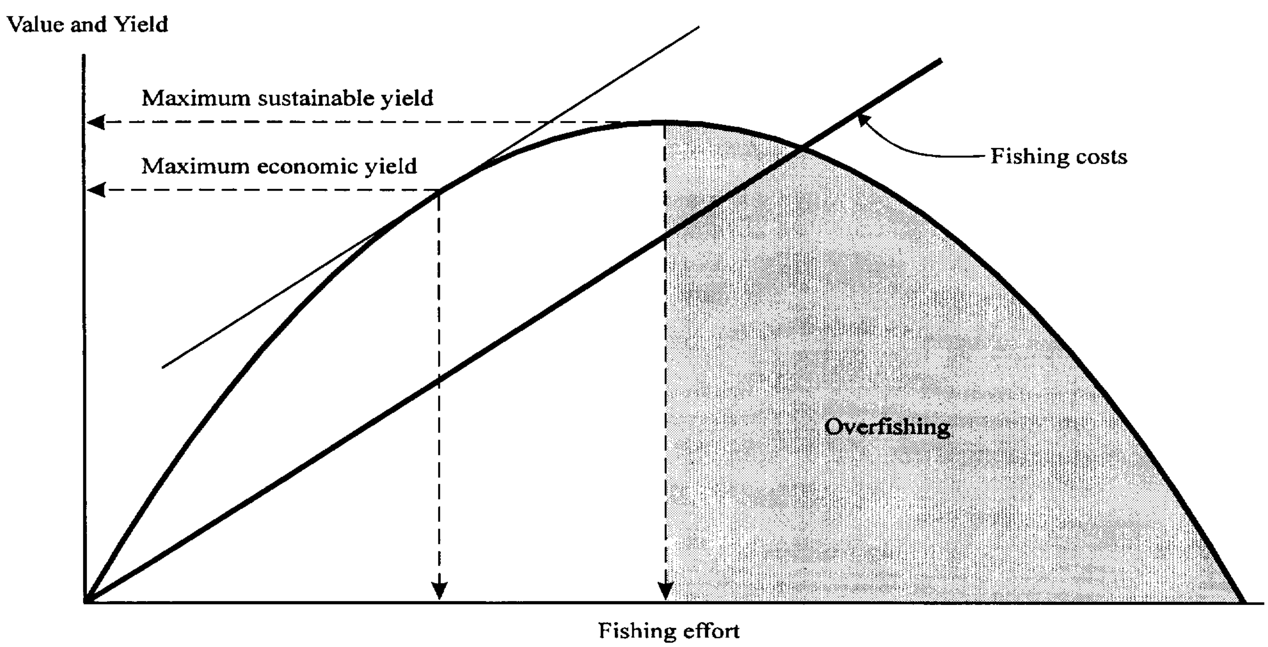
Present fisheries operations at all scales are economically inefficient. Overcapitalization and economic overfishing are significant problems in both developed and developing countries (see Trinidad et al. 1993 on the Philippines fisheries for small pelagic species; Ahmed 1991 on the riverine fisheries of Bangladesh; and Solorzano et al. 1991 on 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 of 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, the products of fisheries and aquaculture are heavily traded goods. In 1990, 10 countries (Denmark, France, Germany, Hong Kong, Italy, Japan, Spain, Thailand, the United Kingdom, and the United States) each imported more than US$1 billion of aquatic products. Thirteen countries exported more than US$1 billion of aquatic products (Canada, Chile, China, Denmark, France, Iceland, Indonesia, the Republic of Korea, the Netherlands, Norway, Thailand, the United Kingdom, and the United States) (FAO 1993b).Trade grew from 32 percent of world production in 1980 to 38 percent of world production in 1990 (FAO 1993b). By comparison, only 4 percent of rice and 22 percent of wheat are traded.

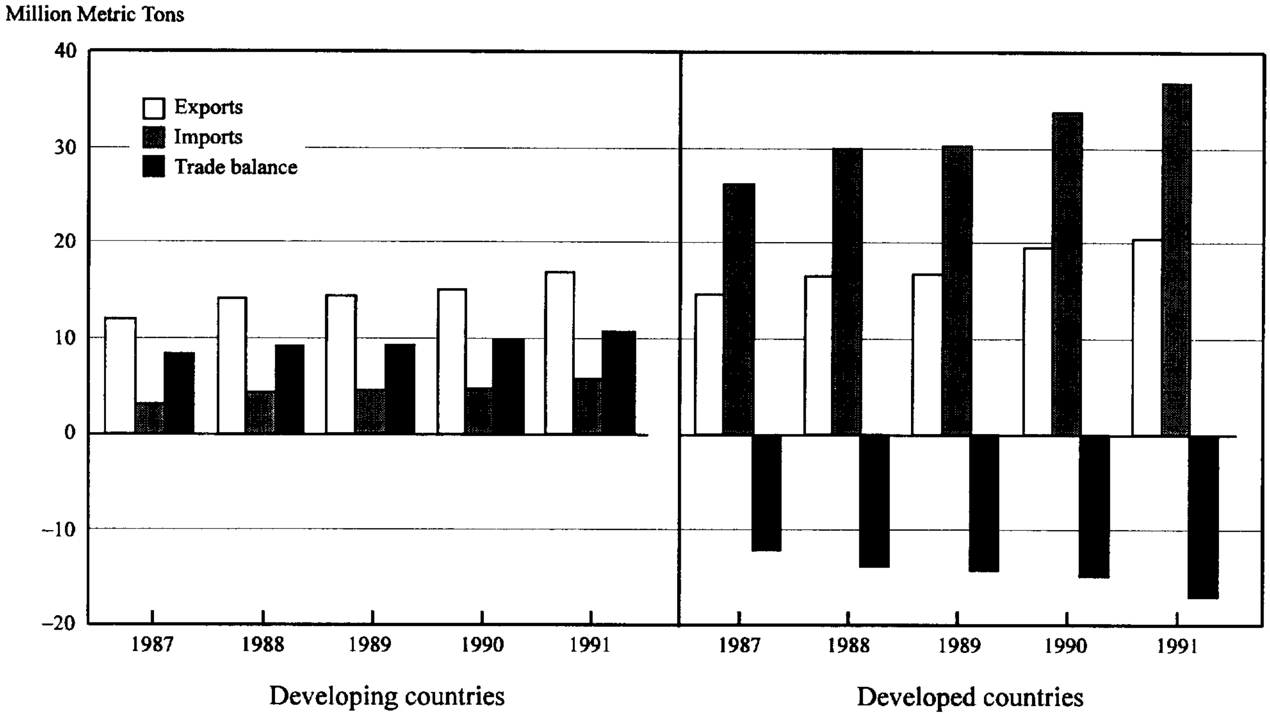
On balance, the developing countries export more—most of it to the developed countries—than they receive in imports, and this trend is likely to continue (Figure 11). This is the reverse of trade

Figure 10—Biological and economic overfishing



Source: International Center for Living Aquatic Resources Management (ICLARM).

Figure 11—World trade in fisheries products, 1987–91



Source: FAO 1993d.

patterns for many other food commodities, especially cereals, for which developing countries are net importers. In the near future, developed countries will continue to be net importers of aquatic products unless they increase their aquaculture production dramatically or unless overall production in developing countries declines sharply. The 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. 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 makes economic sense to conserve fisheries resources only 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. Thus, if purely economic considerations apply, many resources with low productivity would be "mined" and the economic gains invested to realize greater returns on capital elsewhere.

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

Prices of fish have risen faster than those of 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; examples are tuna burgers, various surimi products, and fish fingers.

As market prices have risen, low-income fishers and fish farmers have started to sell more of their production in markets. Unless their own production increases, they must resort to consuming only smaller and lower-market-value fish in the household, thus lowering the quality of the fish they eat (Hossain and Afroze 1991; Brummett 1994).

Although consumers have been disadvantaged by rising prices, producers also are disadvantaged by the cost structures of their sector. Garcia and Newton (1994) conclude that fisheries resources are severely underpriced relative to the costs of catching by an overcapitalized sector. For world fisheries to become economically viable at 1989 fleet levels, either prices would have to rise by 71 percent, or costs would need to be lowered by 42 percent, or some combination of raised prices and lowered costs would need to take place.

About 30 percent of world fisheries production goes to animal feeds in agriculture and aquaculture (FAO 1993d). Chamberlain (1993) estimates that the world aquaculture feed market in the year 2000 will demand 4.6 million tons of fish feed, 1.2 million tons of fish meal, and 0.4 million tons of fish oil, increases of 56 percent, 50 percent, and 77 percent, respectively, over their 1990 amounts. These projections are based on the extrapolation of current production trends for the main cultured species and thus reflect production of a high proportion of carnivorous and omnivorous species such as 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.

The marketing of seafood is challenging because of the product's seasonality, perishability, and variety. The challenges and opportunities are addressed internationally by a comprehensive global trade information system (made up of the GLOBEFISH, INFOFISH, and other regional 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 and social, cultural, and economic organization have helped shape the present transition in fisheries. Weber (1994a) estimates that 14 to 20 million people are involved directly in small-scale fishing, and ICLARM (1992) finds that about 50 million are 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 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 earning a livelihood. 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 work for themselves with minimal gear or can sell their labor 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 income generation. The competitive nature of many fisheries, especially under scarcity, makes cooperative social investment more difficult. In such a situation, economic development may be linked to the accumulation of so-called social capital in a society, where social capital is the sum of cooperative, mutually supportive relationships, obligations, and dues among people (Putnam 1994).

Small-scale fishers have little political influence compared with large-scale fishers and other sectors of the economy. Pauly (1994a) describes 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), the Bangladesh Flood Action Plan (Pearce 1994), and 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 exceptions, women's roles consist of 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 other commitments. For example, Hviding (1993) found no women enrolled as participants in village trials for giant clam culture in the Solomon Islands, causing him not only to speculate on how this situation could be changed but also to remark that these women had little spare time owing to their other duties such as gardening, gleaning, and collecting firewood. In Bangladesh, however, women usually are not permitted to do a range of field work or to go to the markets and thus have some spare time for fish husbandry. Some ICLARM trials in small-scale pond aquaculture in Bangladesh have had up to 60 percent women participants.

All scales of fishing, from artisanal to large industrial, are dangerous because of a combination of vessel layout and the 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 owners who use poorly paid, very young fishing crews. These practices 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 nineteenth and early twentieth centuries than the last decades of the twentieth century.

The Environment and Climate. Like other biological production industries, fisheries and aquaculture depend heavily upon climate and the environment. In many parts of the world, especially the developing world, environmental quality is deteriorating, inevitably affecting production potential. Some fisheries and aquaculture practices also contribute to the decline in the quality of the environment. Laevastu (1993) points out that fluctuations in natural fisheries resources may be caused by ocean climate, pollution, the effects of fishing and other human activities, and ecosystem processes such as predation and disease.

Aquatic ecosystems are generally less well understood than their terrestrial and atmospheric equivalents. A key environmental concept is the functional integrity of the resource system, particularly that required to maintain habitats and sustain production. For example, compared with terrestrial systems, researchers 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 and grasses), aquatic systems may be structured around more mobile habitat features such as phytoplankton and zooplankton, water temperature, water quality, and currents. Because of the mobility of many aquatic features, 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 based on large sessile features, such as reefs, mangroves, and seagrass beds, have habitat features more akin to those in terrestrial systems.

Aquatic systems are the eventual sinks for all terrestrial and atmospheric pollutants. Contamination from heavy metals, organic and inorganic chemicals, and harmful algal blooms is increasing worldwide, in the developing as well as the developed world, leading to large economic and food losses and some loss of lives (Hallegraeff 1993; Maclean 1993; Corrales and Maclean 1994). 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 food or trophic chain than the terrestrial animal equivalents used for food, they average two full trophic levels above primary producers. Direct removal by fishing will therefore change natural systems by altering the abundance of higher-order predators in food chains. Many fishing practices modify habitats: for example, bottom trawling removes some living communities, disturbs sediment, and catches many incidental species; deployment of fish-aggregating devices, by their shape and attached biological communities, attract pelagic surface- and midwater-swimming species such as tuna and mackerel. Aquaculture can also pollute the environment, affecting its own viability and that of surrounding agricultural systems.

Aquatic systems, which cover more than 70 percent of the Earth's surface, have major influences on global climate through the hydrological cycle (water heats and cools the environment through its various forms as vapor, clouds, liquid, snow, and ice) and through their part as sinks of about one-third of anthropogenic carbon dioxide (Chahine 1992; Siegenthaler and Sarmiento 1993). Likewise, aquatic systems themselves are influenced by climate and climate change. The 1982–83 El Niño, for example, raised sea surface temperatures by 5 degrees Celsius in some parts of the Pacific, limiting primary production and causing large changes in fish abundances (Laevastu 1993). The effect of the present protracted El Niño event, which commenced in 1991–92, on global fish production has yet to be examined. Inland pond aquaculture, like agriculture, is directly affected by climate, especially rainfall and temperature, stream runoff, and general water availability.

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 that 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, fresh for sashimi (raw fish), frozen, dried, fresh for cooking, or canned. Often the products that have undergone the least postharvest processing (for example, live or sashimi fish) obtain 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

Anticipating the outcome of the transition requires addressing five issues: use, resource management, intensification, integration with other sectors, and national versus international interests. These issues, which are relevant for all countries and resources, interact with each other. For example, options for better use are of no value to a small-scale fisher who has no security of access to aquatic 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 Use. Living aquatic resources, now mainly harvested directly for human food, offer perhaps the greatest range of potential uses of any biological resource. Users should seek the best possible economic, social, and cultural use of the resource. 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.

Researchers and users need to keep open minds on how best to use living aquatic resources for sustainable food security. Such resources can be used directly as high-quality food and indirectly for other economic ends such as livestock and aquaculture feed; crop fertilizer; jewelry (pearls and shells); recreation (game fishing, diving, and ecotourism on coral reefs); food additives (carrageen from macroalgae); additives in the production of cosmetics, shampoo, detergents, and industrial lubricants (macroalgae); bases for production of industrial, medical, and other chemicals via the application of marine biotechnology; and protectors of the environment, such as mangroves, which protect tropical coasts (Norse 1993, Table 3).

Nonfood uses are of two types: those that obtain lower prices than fish sold for human food, such as fish meal, and those that fetch higher prices than human food, such as pearls. As contributors to food security, the latter are usually more important than the former, although the former also make 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 fish meal and fish food for aquaculture could diminish if plant protein substitutes are developed rapidly. Alternatively, 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.

Another dimension of use in aquaculture is the timing of returns on investments. Sometimes a use other than for human food brings earlier returns; for example, ICLARM's clam research shows that cultured giant clams in coral reef lagoons take about 7 years to reach the best size for the high-value adductor muscle market in Asia. At 6 to 12 months, however, the clams can be harvested and sold to the marine home aquarium trade, and at 24 months they can be used for sashimi, thus bringing in earlier cash flows for village producers. The effect on food security is positive since any losses to the Hong Kong restaurant trade will not result in starvation but will give the village producer money to buy staple foods or to reinvest.

Reducing postharvest losses is a direct and immediate way to improve use. Losses can be minimized by better handling of the product and the development of aquaculture species and strains that travel 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 postharvest operations than in fishing vessels and gear. However, the scale of infrastructure investment for postharvest handling should match the size of the

Table 4—Possible uses of living aquatic resources by peoples in the developing world: Economic returns and employment prospects

Use	Economic and Cultural Value	Employment Prospects
Extractive uses		
Fishing for human food	Low to high	Low to high
Fishing for animal feed	Low	Low
Gathering for traditional medicines	High	Low
Gathering for jewelry and ornaments	High	High
Gathering or culturing for ornamental/aquarium trade	High	Moderate
Bioprospecting for new chemical uses	Low to high	Low
Aquaculture for human food	Low to high	Low to high
Aquaculture for industry additives (such as food, cosmetics, and lubricants)	Moderate	Moderate
Recreational and sport fishing	High	High
Oils	High	Moderate
Chitin	Low	Low
Leather, skins	High	Moderate
Conservation uses		
Marine protected areas	Low to high	Low
Ecotourism, diving, underwater photography, whale watching	High?	Moderate
Tag and return gamefishing	High	Low
Saving biodiversity in the world	Low to high	Low
Environmental services		
Biocontrol in ponds and rice fields	Low	Moderate
Diversification of small-scale agriculture to improve farm productivity and reduce risk	Low	High
Integration of aquaculture with agriculture to improve on-farm resource cycling	Low	High
Integration of aquaculture with agriculture to improve soil fertility and crop productivity	Moderate	High
Animals and plants as filters of excess pollutants and nutrients in water systems	Low	Low
Cultural services		
Religious value	High	Low
National icons, identity	High	Low to high

Source: ICLARM estimates.
Note: Where a range from low to high is shown, the importance varies with the particular use.

resource it has to handle. Large freezer plants, 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 use of resources. Market demands are changing rapidly, whether the market is a household that 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 small-scale producers sell more fish, the effects on producers' household nutrition should be studied. In a review of studies on the effects of agricultural commercialization on household nutrition, Kennedy and Bouis (1993) show that increased income does improve nutrition but usually at a slower rate than expected. The studies concluded that health, education, and sanitation programs 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 with purchased grains in the diet may lower intake of protein and trace elements (such as vitamin A). In small-scale aquaculture, Gupta and Rab (1994) showed that the 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 and conservation status 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 is being phased out 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).

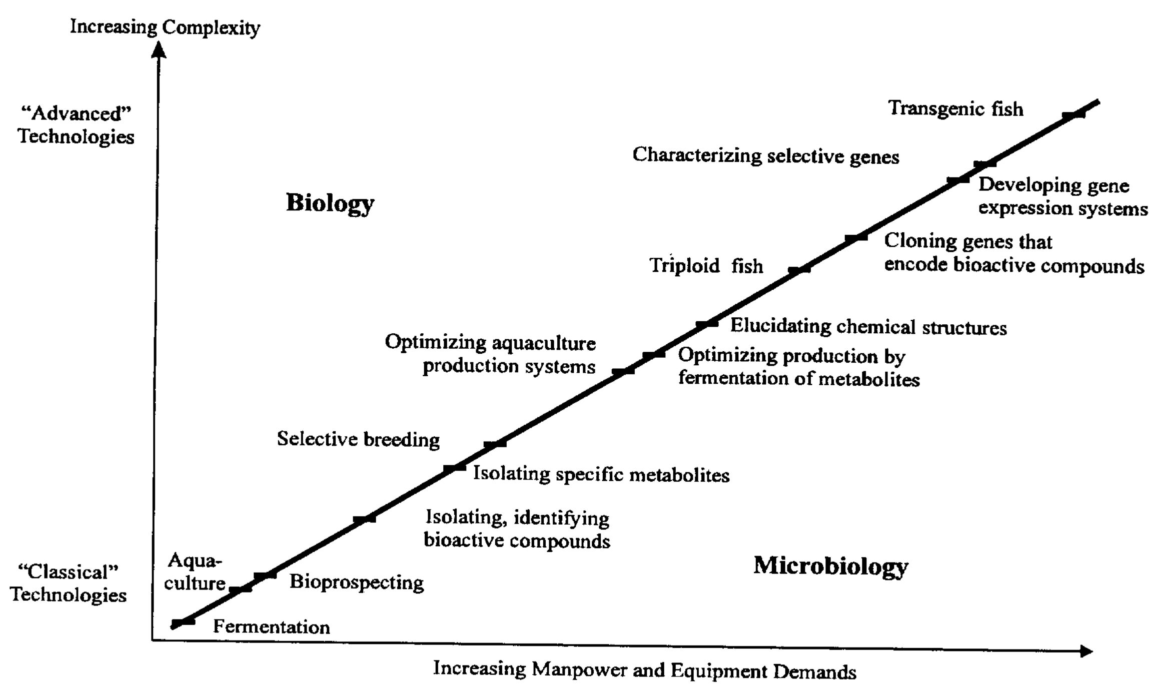
Aquatic organisms may have alternative uses, including a wider range of nonfood uses. Some nonfood uses have significant prospects for improving national economic welfare, and a few may improve household welfare for low-income people. Zilinskas and Lundin (1993) reviewed how a range of simple and high-powered marine biotechnologies could be applied in developing countries subject to technical manpower and technology requirements (Figure 12). Alternative uses of the same resource often conflict with each other. For example, several different fishing operations compete for the limited shark resources of the Maldives, along with tourism for shark watching (Anderson and Ahmed 1993).

Employment prospects for various uses 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. Such enterprises may not produce large total numbers of fish, but they could improve household food security because farming systems and biodiversity studies indicate that more diverse, integrated farming systems lead to greater total productivity and stability (Guo and Bradshaw 1993; Baskin 1994).

Resource Management. 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 that 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 from exploiting the resource beyond sustainable limits and thus producing resource scarcity (Oakerson 1992). Homer-Dixon, Boutwell, and Rathjens (1993) recognize three causes of resource scarcity: change in resource levels, population growth causing reduced per capita availability, and unequal distribution that induces scarcity for some users.

Many fisheries resource management arrangements have not succeeded in coordinating and restraining use. They have not kept pace with the technological ability to exploit the resource or with the driving incentives to exploit—economic returns, population growth, food, and employment. Manage-

Figure 12—Gradient of marine biotechnology



Source: Adapted from Zilinskas and Lundin 1993.

ment 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 of 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 with "the tragedy of the commons," thereby focusing on the creation of individual property rights rather than on limitation of 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 attempt to limit access has led to schemes to limit the number of fishers by regulated licensing and input restrictions (such as constraints on gear, vessel size, and days fished) and the creation of output restraints such as quotas that may be granted or sold as quasi private property (for example, 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 claim legitimate access to the diminishing resources. Many small-scale fishers also pursue activities other than fishing, often in the agricultural sector, but much more needs to be done to find other activities for users. A recent World Bank study highlighted the lack of attention to managing an excess of fishers and fishing units in overexploited fisheries and drafted guidelines for a working group on alternative livelihoods for fishers (John 1994).

Equity is an important dimension of resource access and exit from the fisheries sector. In the developing world, small-scale fishers frequently lose out to industrial-scale operators favored 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 values, such as economic efficiency, may have to be traded off for equity.

The failure to coordinate and restrain resource use is clear from the increasing scarcity of resources and the growing level of conflict over rights and their distribution. Declines in the resource exacerbate conflicts among users from the local to the international level (such as in the Philippines [Luna 1995] and in Asia [Richardson 1994]). Policymakers thus 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). 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).

The path to better resource management is not clear, however, and a global research project has begun to investigate the application and potential of comanagement practices 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 are formally giving local citizens groups a greater voice and more responsibility. Decisions are brought down to levels more appropriate to the functioning of the resource and social systems. In some systems, these actions may have been a belated recognition of former tenure arrangements that 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 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 that 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 its own resource management issues, especially concerning access rights. Small-scale farmers with entitlement to their land have greater security of tenure than capture fishers. But the farmer must compete for scarce water resources with agricultural, 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 in, for example, rice-growing parts of Asia and 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 nongovernmental organizations (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 laborers 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 1994).

Coastal aquaculture will face severe competition from other resource users for suitable sites and will therefore experience some of the problems of common property resource management. The growing concentration of large urban centers and populations in the coastal zone reduces the quality of the environment and increases the competition for access (more than half the world's population, and a greater proportion in some regions, lives within 100 kilometers of the sea). 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 present cultivated land, is essential to alleviate poverty. Terrestrial environments are most commonly degraded by people driven by poverty to overexploit natural resources. 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.

Now, in the case of capture fisheries, economic incentives, technological developments, ignorance of biological limits, and poverty all contribute to the intensification of exploitation (that is, an 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 sustainable limits, however, yields begin to fall as the productive capacity of the resource declines (see Figure 10). Users rapidly reach the limits of sustainable exploitation not only with mechanization and the deployment of industrial-scale fleets but also when the number and capacity of small-scale fishers are 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 as long as the world still largely depends 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 effects on biological processes (such as breeding, migration, and feeding) 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 the fishing of 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 effects on coral reefs.

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. There are already examples in both developed and developing countries of culture practices that 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. Intensification of shrimp (marine prawn) culture in several Asian countries (China, Indonesia, the Philippines, Taiwan, and Thailand) led to severe environmental and disease problems resulting in production crashes from which many sites have not yet recovered (see Environment and aquaculture 1994). Inadequate scientific knowledge of the consequences of many of the farming practices, outbreaks of new and existing diseases because of poor hygiene and quarantine, and lack of control over pond effluent intakes and outlets all contributed to irreversible crashes in production on many farms, some after only two or three years of production. Some, such as those in Taiwan, where shrimp production fell from over 80,000 tons per year in 1987 to very limited production in 1991, still have not recovered (FAO 1992c).

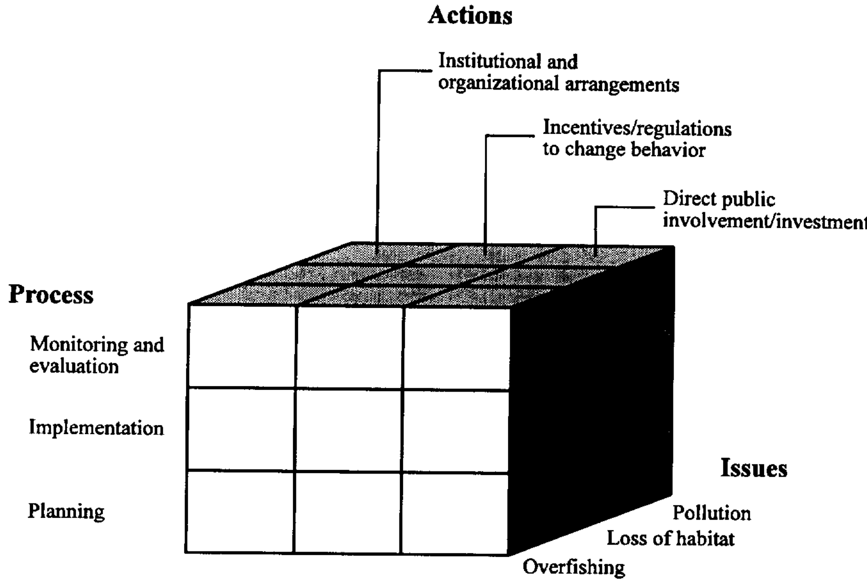
Aquaculture production is governed by a similar range of environmental, climatic, resource (space, inputs, and labor), pest, disease, and technological constraints as agricultural and livestock production. However, land and suitable-quality water are increasingly scarce; competition with other users for suitable land, sites, and water will hamper increases in aquaculture production. 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.

Two forms of production intensification combine the techniques used in wild fisheries and aquaculture. The first is stock enhancement, wherein hatchery-reared or captured fry, larvae, or seeds are placed into a natural environment to grow out and be harvested later as wild stocks. The success of such schemes, including the effects on the genetic diversity of wild stocks, is still being debated (Hilborn and Winton 1993; Munro 1994). The second form of intensification involves growing out collected juveniles, especially of high-value species, in cages, ponds, or racks and selling them in peak condition at the top of the market. Both forms are suitable for some low-input systems. The first method has been pioneered successfully with giant clams in the Pacific (Fitt 1993). Blacklip pearl oyster production in the western Pacific relies on enhancement technology (that is, collecting spat from the wild and growing them on special marine farms), 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. For too long fisheries and aquaculture have been treated as sectors in isolation, a practice that has ignored important linkages and externalities. To anticipate the possible consequences of the current transition, it is important to recognize 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. Many fisheries problems and solutions to those problems thus lie outside the sector, in overall community and economic development (Smith 1979; Johnston 1992). Vertically integrating small-scale fisheries development could escalate problems by isolating the sector from others providing better opportunites and by causing overinvestment in fisheries, which may lead to biological overfishing and collapse of the whole sector (Emmerson 1980).

Researchers are beginning to address the need for an integrated approach to management of aquatic resources. The schema developed by Scura et al. (1992) for integrated coastal zone management shows the complexity of issues in one fisheries system—the coastal zone (Figure 13). Integrated coastal zone management addresses the goals of sustainable development by seeking to maintain the functional integrity of the resource system, reduce conflicts over resource use, 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, referring specifically to hydrology, material flows, nutrient flows, and energy. Wilson et al. (1994) conclude that sustainable fisheries appear to require maintenance of

Figure 13—Integrated coastal zone management



Source: Scura et al. 1992.

all basic biological processes such as breeding, migration, and feeding.

In recent years, researchers have developed tools such as coastal transects (Pauly and Lightfoot 1992), geographic information systems and system analytical models such as ECOPATH II (Christensen and Pauly 1993), and bioclimatic and fisheries oceanographic modeling to study whole systems or parts of systems. To date, however, research has concentrated only on biophysical tools. 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 (for example, Sherman, Alexander, and Gold [1993] examine the large marine ecosystem concept).

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 resources and their ultimate contribution to sustainable food security. Systems thinking is likely, however, to help identify the gaps in fundamental knowledge that are key to the better functioning of the whole system. Policy development, institutional linkages, and communication among government agencies, NGOs, and researchers at local, national, and international levels should help improve decisionmaking.

National versus International Interests. More than most other food commodities, aquatic resources generate tension between national and international interests 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 1982 United Nations Convention on the Law of the Sea (UNCLOS) was the nationalization of fishing capacity, a process that is continuing today, for example, in Indonesia (McBeth 1994). With the exception of such fisheries as the western Pacific tuna fishery, largely in the exclusive economic zones of the Pacific island states, fishing within the exclusive economic zones is increasingly becoming the reserve of national fleets often enlarged since declarations of exclusive zones. Distant-water fishing countries are more restricted in access than ever before. At the same time, countries such as Japan have compensated by increasing their imports. The experience of UNCLOS, however, shows that many countries must greatly strengthen their capacity for managing biological resources. FAO (1993e) reviewed the effects of the first 10 years of UNCLOS on fisheries and concluded that the results were disappointing and could not be expected to improve until countries practiced better domestic fisheries management.

UNCLOS first provided some backing for extensive national ownership of aquatic resources. Akin to UNCLOS, the 1993 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, Burhenne-Guilmin, and Synge 1994). It calls for countries to link sustainable use and conservation and to protect and encourage customary use of biological resources. 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, a global database of information on fish (FishBase 1995).

Trade is changing the patterns of consumption of fish. Like small-scale agricultural producers in the developing world, fisheries and aquaculture producers are often significant consumers of their product. Prices of fish on world markets are increasing as supplies stagnate and 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 and will thus not share in the benefits of increased commodity prices and will suffer nutritional and employment losses (Pauly 1994a).

The Contribution of Living Aquatic Resources to Food Security during the Transition

Sustainable food security is not achieved through any single, simple solution but requires (1) a sufficient, stable, predictable, and sustainable supply of food; (2) access to food; and (3) nutritional adequacy. Living aquatic resources can best help meet each of these needs if countries go beyond fisheries and aquaculture to capture much greater, more enduring benefits from the use of the resources.

Stable, Sustainable, Predictable Supply

The contribution of living aquatic resources to food supply is deteriorating as the gap between supply of and demand for living aquatic resources grows. 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 protection of the regenerative potential of natural stocks; maintenance of high-quality, high-diversity options for the genetic resource base for aquaculture; and protection of the integrity of ecosystem functions in natural and artificial production systems. Keeping aquatic ecosystems healthy means improving environmental practices on adjacent land and in watersheds. In addition, 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, and appropriate technological and natural resource knowledge. Good management therefore requires partnerships and clear definitions of the interests and responsibilities of governments, resource users, researchers, and the community, including users of the commons.

Predicting the level of sustainable fish supply requires much better knowledge of the fisheries resource base, the dynamics of aquatic ecosystems, and the effects of climate, habitat degradation, and pollution. Achieving this knowledge will take a large coordinated effort but offers many benefits. Better resource predictability will greatly improve resource managers' capacity to manage and fishers' capacity to target catching more efficiently. Research in this area should therefore begin immediately.

None of the above can be achieved without concerted national and international management action and increased investment in scientific research. 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 that are most dependent upon living aquatic resources. Should these suffer collapses like that seen in Canada's Grand Banks cod fishery, the consequences will be catastrophic, for 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 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. The allocation of such rights 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 becomes more difficult as the world's fisheries resources diminish and more people wish to use them. Authorities should be planning more adjustment studies, alternative livelihoods for fishers, and development projects in anticipation of increasing scarcity.

Small-scale fishers should be empowered through a greater degree of organization, more 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 since they could have an immediate effect on supply by improving postharvest quality. Women should be given increased access to capital for aquaculture and small-scale postharvest operations.

For low-income urban and rural fish consumers, price will also determine access to the resource as food. Minimizing the supply-demand gap and improving the economic efficiency of production will help producers get a fair price and consumers 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 to improve fish supplies and the many other environmental services provided by on-farm ponds and fish. Large policy steps and research investments are required now to help realize the full benefits of these technologies without causing environmental damage.

Adequate Nutrition

The transition threatens nutrition in low-income households. In developing countries where aquatic products are currently important dietary items, the supply and disposition of these products is a particularly critical issue. Policymakers should initiate nutrition studies and establish health education programs now to ensure that as household fish supplies diminish as a result of lower production or reduced market purchases due to higher prices, they are replaced by other nutritious foods.

The growing supply-demand gap should be used to stimulate greater efforts in postharvest quality control and thus provide for better quality and quantity of fish supplies.

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—that is, in 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 that the majority of production will come from aquaculture.[7] At least another 25 years will be required to achieve that level. The challenge is to maintain present or near-present levels of natural harvest while sustainably increasing aquaculture production.

[7]This study does not attempt a detailed assessment of likely global production. Such an assessment requires a serious modeling effort based on assumptions about trajectories of various natural resources, the likely gains from aquaculture, and the trade-offs 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 that an increase of 25,700 tons was possible under ideal management conditions and with full conservation of critical habitats, including coral reefs. No parallel assessments have been attempted for aquaculture.

All present indications are that production by capture fisheries will be below its present level in 2020. At best, it will maintain its present level. Gains from better handling of catch, more use of bycatch, and the exploitation of the few remaining underused 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 concern the apparently cyclic rise and fall of some of the largest fisheries stocks due partly to ocean climate factors (such as El Niño events and other large-scale patterns): it is unclear which existing fisheries will collapse and 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, these tropical fisheries decline gradually though surely, their species composition changing to favor smaller species lower on the trophic scale. The end point 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 uneven in their development, depending on the political stability of national governments, pressures from foreign fleets, and the resilience of stocks. Greater coastal fisheries development will occur in Africa but will be hampered by growing coastal pollution and habitat destruction. The fisheries of the great lakes of Africa will be subject to continuing large changes in species composition and likely greater efforts to privatize the control of resources.

In all regions, more fisheries will be enhanced by the release of hatchery-reared seed. Coastal sites, inland streams, dams, and reservoirs will be used to raise fish.

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 through increased production from existing systems. In both inland and marine waters, however, other agricultural, industrial, and urban activities will compete vigorously for high-quality water, space, and other inputs such as feed, fertilizers, labor, and capital.

Major setbacks will occur from time to time as a result of disease, pollution, and poor management practices. These problems 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 and strains of species for aquaculture, to domesticate new species, and to prevent environmental and disease setbacks. The rate of progress will depend on developments in the research pipeline and on the time required to produce new results and, through good early partnerships with farmers and industry, to translate these results into viable practice. For example, genetic improvements in fast-growing species such as tilapias still take at least 5 years to produce and 2 to 5 years to disseminate safely onto farms. Genetic improvements in 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 Sub-Saharan Africa in aquaculture. Sub-Saharan Africa will develop slowly for some time to come. Small-scale integrated aquaculture-agriculture will become more widespread. Commercial, market-oriented aquaculture will also develop in certain sites, such as near cities and tourist destinations. A major development effort that is sensitive to socioeconomic and cultural conditions in the agriculture sector is required to increase the practice of aquaculture in Sub-Saharan Africa. Climate and climate variability will also be critical in Sub-Saharan Africa, for many of the enterprises will rely on rainfed ponds or relatively abundant irrigation water. Low-input, integrated aquaculture-agriculture offers the promise of sound and sustainable resource management but requires a greater level of knowledge than do traditional agricultural practices.

Some countries in the developed world are establishing intensive, high-capital, high-technology offshore aquaculture systems or onshore closed systems, including complete recycling linked to other industries, such as the brewing and waste management industries. These systems are being designed to overcome the negative environmental side effects of aquaculture as well as to help solve the environmental problems of the other industries. The costs of inputs are often high, and profitability depends on high market prices for products.

In 5 to 15 years, many of the major carnivorous aquatic species raised in aquaculture will be fed on diets free or almost free of fish meal as nutrition research develops digestible alternatives providing the correct balance of amino acids and other dietary essentials. These alternative feeds will not remove all problems of feed supply, but they 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 aquaculture conditions and with desirable growth and market characteristics.

The Biological Resource Base

Capture fisheries and other human activities will continue to degrade the diversity and abundance of aquatic resources. This resource degradation will have a negative effect not only on capture fisheries production but also on the raw material for culture. In aquaculture systems, more production will come from fewer species as the knowledge of how to raise the main species grows. However, some new species will be brought into production and a wider range of strains of existing aquaculture species will be developed.

Concern about the safety of introducing new species 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 that time suitable arrangements should have been negotiated to free up access to germplasm more safely and equitably.

More conservation areas will exist than at present, but the size and number of such areas will still be below critical levels to protect major species, biological and ecological functions, and habitat diversity. Too little is yet known to design adequate aquatic systems of protected areas for conservation. Key questions such as the location, size, and shape of protected areas need serious scientific study.

The Geography of Production and Consumption

The developing world will continue to lose out to the developed world in fish consumption. As more capture fisheries become overexploited, total production in the developing world will slow down. Exports from the developing to the developed world will continue to rise, and as the population of the developing world burgeons, fish will become even scarcer for the poor of the developing world.

Suitable climate, water, space, capital, labor, 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, India, Indonesia, the Philippines, Thailand, Vietnam, 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, the Indian Ocean, and the 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.

The 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. 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 stimulating the development of aquaculture. High prices will continue to cause conflicts between aquaculture and alternate land uses, especially agriculture. Aquaculture will also compete for fresh and salt water. Because of the high capital needs of some intensive aquaculture enterprises and the high price of fish, aquaculture will be controlled by large investors and will outcompete other land uses. Coastal shrimp ponds are being constructed on former coastal rice lands throughout humid Asian regions. In the Philippines, shrimp ponds have recently been exempted from the major agricultural land reform program that 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 heavily 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 as a result of the often conflicting demands for keeping costs down, creating employment, maintaining product quality and sanitary standards, and protecting human health.

Trade liberalization under the General Agreement on Tariffs and Trade (GATT) will generate trade wars and alternative 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 dictated by the needs of the market. 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 prevent the worst consequences of dispossession and nutritional shortfall.

Many fewer people will be dependent on capture 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 have greater control over 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 1994). Commercial fishers often will cede access to small-scale artisanal fishers as the social, political, or resource situation dictates. In other cases, fewer commercial fishers operating more efficient gear will dominate.

Many more people will participate in aquaculture, although they will often be employed in capital-intensive ventures. Small-scale farmers in Sub-Saharan Africa and Asia will participate part time. Technical extension programs related to aquaculture 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 than at present in terms of hatcheries, buyers, equipment, and other input supplies in much the same way that the agriculture sector has now become increasingly privatized in these countries.

The Environment and Climate

Over the next 25 years, the aquatic environment will feel increasing effects from terrestrial activities, habitat alteration, and climate change.

Climate is one of the greatest unknowns concerning capture fisheries, since even small shifts can have critical effects on the 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 degrees Celsius between the 1930s and the 1990s at one site in California benefited 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 given that 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 the harsh household impacts of drought by producing fish and providing water for other farm activities such as cultivation of crops.

Freshwater will become a critical issue for all countries and peoples. The quantity, quality, and disposition of freshwater will be increasingly altered by direct use, pollution, construction of dams, draining of wetlands, irrigation, salinization and biodegradation through eutrophication, harmful algae blooms, 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 and the growing economies in Latin America and Africa take measures before too much damage is done?

Marine, especially coastal, water is increasingly affected by human activities, and these effects are 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, remediation technologies from the developed world will be applied in developing countries, but gradually new and more appropriate ones will be developed.

Postharvest

The obvious limitations in the supply of aquatic products will lead to a greater emphasis on better postharvest use. Market forces will dictate the production of convenience foods (for example, frozen and breaded fish and surimi products) and novelty products (such as rarer species). Convenience foods will be generic and not specific, whereas novelty products will tend to emphasize their origins, such as Shanghai freshwater crabs. Greater use will be made of byproducts (skin, bones, fine oils, and shells) and bycatch or incidental species. Realizing these uses will require investments in research.

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. Understanding the roles and history of recent aquatic resource research can help researchers develop the most appropriate role for future research.

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 prevent further degradation of the resource base and to begin to rebuild fisheries. That fish stocks have declined and some have collapsed despite scientific warnings shows 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.

The History of Aquatic Resource Research

To date, research for aquatic resource management has consisted mainly of 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.[8]

Fisheries science has been dominated by biological sciences since it grew out of nineteenth-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 stocks. Smith (1994) argues, however, that fisheries science adopted too narrow an approach, concentrating on 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 are hampered by the aquatic environment, which tends to produce a greater degree of unpredictability than the terrestrial environment in the abundance and distribution of resources (Gulland 1986). Some speculate whether the systems are chaotic or complex, but either case causes 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 programs of the last two decades.

[8]Professional meetings of fisheries scientists are signaling the need for new approaches to resource management and science. 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 entitled "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 Union and Atlantic Canada.

Assessments are often thwarted by a lack of good data. Many fish stocks have gone from a stage of early development to overexploitation before sufficient information could be collected for sustainable management. Tropical and developing-country resources almost universally lack the long history of data required by most advanced fishery assessments.[9] Fisheries data are difficult and expensive to collect, especially for artisanal and small-scale fisheries. Thus 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 gears 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, information on the resilience of different stocks to exploitation is inadequate (Mace and Sissenwine 1993). Indeed, biologists are only now converging on a consensus about what constitutes a key biological reference point for sustainable fisheries resources, namely, a level of spawning that will prevent recruitment decline over time (Sissenwine and Shepherd 1987; FAO 1993f; Myers and Barrowman 1994).[10]

Research has yet to answer many other questions as well. 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 effects 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) developed much more recently than fisheries biological science and has only recently gained 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 (Smith and Pauly 1983); many other research institutions are now considering the need for multidisciplinary work.

Another new tool of key importance to assisting natural resource managers is policy research. Policy research can both inform and shed light on the process of policy development, drawing lessons and leading to new models. Such research has had profound effects on national governments in fields such as agriculture and is starting to have an effect in the developed world on fisheries and aquaculture.

Four Roles for Aquatic Resource Research

Research can play at least four roles in assisting natural resource management. First, it can produce 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.

Second, research can identify 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; and environmental research may reveal unacceptable pollution levels in waters used for aquaculture. The main users of this research are policymakers,

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[9]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. These fisheries are based on resources that are far less diverse than those exploited in most of the (tropical) developing world. In recognition of the huge challenges facing tropical fisheries stock assessments, ICLARM developed a strategic research program in tropical fish stock assessment. This program has been continuous since 1979 and has had a strong impact on method development, software development, and training throughout the developing and developed world; for a summary, see ICLARM 1994.

[10]In fisheries science, "recruitment" refers to entry of young fish to the fishery. It occurs when individuals reach a size or age at which they become vulnerable to harvest.

fisheries managers, fishers and fish farmers, and other researchers. The results of this research should be conveyed in a way that clearly explains 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.

Third, research can help 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 limiting access to the use of the resource affect coastal communities? Will larger mesh sizes for nets 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.

Fourth, research can produce 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 fisheries management in the developed world. 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 usually used 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 (see, for example, Luna 1995 for a case from the Philippines). The users of this type of research are predominantly fishers and farmers but also include 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, research is well targeted to needs through close interaction between researchers and users, and the appropriate mix of social and physical science applies.

The utility of research in fisheries resource management has recently been debated in the scientific literature and at major international conferences. Ludwig, Hilborn, and Walters (1993) argue that sustainable fisheries management is unattainable, as demonstrated by many failures to prevent overuse. They challenge the prospects for achieving scientific consensus over sustainable levels of fisheries resource use and point out that even if achieved, the results of scientific consensus are often not acted on, thus leading to overuse. They doubt that science and technology can provide answers to resource or conservation problems, although they promote adaptive management approaches.

Others argue that science can make a valuable contribution to fisheries resources management. Rosenberg et al. (1993) hold that sustainable resource use is a legitimate concept and, although challenging, is soundly based in scientific resource dynamics theory and is achievable. They illustrate their arguments with examples of successes and failures. They agree with the above authors that many of the failures occurred despite scientific consensus because managers failed to act. They describe new developments in which science further assists managers by assessing risks in the face of uncertainty. Ehrlich and Dailey (1993) describe and support the use of science to perceive natural resource problems, understand their mechanisms, and strategically assess options for their solution.

Strategic Research for Living Aquatic Resource Management

National and international research programs for living aquatic resources need to be reshaped based on the strategic context outlined here—that is, the imperatives of the transition facing aquatic resource users. The most appropriate model for research for living aquatic resources management is what Roussel, Saadand, and Erickson (1991) described as "third generation R & D": research and development that responds to both existing and future needs while contributing to the identification and exploitation of new opportunities and new solutions (Table 5).

Research agencies must overcome the difficulty of raising research funds by considering all costs and benefits (not just financial ones), priorities, and the

Table 5—Third generation research and development model for natural resource management research

Management and strategic context	Has holistic strategic framework consisting of the CGIAR[a] vision for food security and the present transition in aquatic resource use.
Philosophy	Relies on partnership of all actors.
Organization	Breaks the isolation of R & D.
Technology/R & D strategy	Integrates technology/R & D and natural resource management strategies.
Operating principles	Combines R & D and resource management insights.
Funding	Varies with donor/national/local sources, depending on how benefits are likely to be distributed.
Resource allocation	Based on balance of priorities and the risks and rewards of a successful research outcome.
Targeting of R & D	Has defined, consistent natural resource management and scientific objectives.
Priority setting	Based on costs/benefits and contribution to strategic objectives.
Measurement of results	Performed against natural resource management objectives and scientific expectations.
Evaluation of progress	Occurs regularly and when external events and internal developments warrant.

Source: Adapted from Roussel, Saadand, and Erickson 1991, Figures 3 and 4.
[a]Consultative Group on International Agricultural Research.

likely contribution to sustainable food security. In convincing funders of the need to support research, agencies must stress its multiple roles and many different users.

Given the growing gap between supply and demand of living aquatic resources, research must be increasingly anticipatory. Research must look forward to the consequences of present actions or outcomes, guard against negative effects and protect options, foresee and attempt to satisfy future demands, and time itself to maximize its chances of being useful.

Garcia (1992) and Smith (1994) argue that throughout its history, fisheries research both benefited and suffered from its close ties to fisheries management agendas, which are driven by short-term questions. These dictates have generated research opportunities, resources (research is necessarily expensive when work at sea is involved), and questions but have caused frequent changes in research direction and not permitted resolution of fundamental, longer-term 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 studying living aquatic resources should use two principal strategies when devising their future programs: (1) breaking down the isolation of aquatic resource research and development from its uses, and (2) fully using the four roles of research. These strategies will require that more total resources be devoted to aquatic resource research.

Strategy 1: Break the Isolation of Research. Living aquatic resource research must be constantly in touch with the systems within which its work will be used. Such systems include aquatic resource, coastal zone, and water management systems, as well as agriculture. Aquatic resource issues need to be linked with terrestrial resource issues to achieve broad progress toward food security. Integrated systems thinking is already having an effect on research methodology for aquatic resources, but more remains to be done.

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

National and international research systems must be strengthened if they are to support national sovereign responsibilities for aquatic resource management. Strengthening these research systems will require greater networking, training, regional cooperation, and collaborative research.

The barriers between researchers, between institutes, and between research disciplines must be broken down. Fisheries and aquaculture research needs to draw on oceanography, hydrology, sedimentology, climate, marine biology, forestry, irrigation, and general agricultural policy research. Access to knowledge and research resources rather than sole ownership of the research resources (facilities) will be the way of the future. Networks of information and research collaboration will become more common. South-South and North-South linkages can speed access of agencies to the latest scientific findings and methods.

Biological research in fisheries and aquaculture is integrating with other biological research at the molecular level, particularly in genetic identification of stocks and genetic diversity, research on the aging of fish, and studies of basic biological processes.

Strategy 2: Use the Four Roles of Research. Recognizing that research fulfills different roles—it generates knowledge, identifies issues and implications, helps resolve conflicts, and provides solutions and new options—offers 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 they break the isolation of research, researchers have a greater chance of getting their messages across to those that will use them and of understanding the needs research can address. They can therefore play a part in resolving a conflict, study the implications of a policy change, develop new ways to manage fisheries resources, or enhance farm productivity.

Nowhere is this more important than in the developing world fisheries. The aquatic transition in the developed world has received global attention (one example is the collapse of the Grand Banks cod fishery), but little attention has gone to events in the developing world. Researchers now should be working to analyze, anticipate, and highlight transitional events and their likely effects in the developing world.

The Enabling Means: More Resources for Aquatic Research. Aquatic resource research has long struggled for attention against more visible priorities on the land. The resources, and therefore research and management needs, have tended to be "underwater," out of sight and out of mind. But as aquatic environments and their biota begin to show the global effects of terrestrial and atmospheric insults as well as of direct use, the need for aquatic resource research is becoming more visible.

A number of factors point to the need for a heightened emphasis on aquatic resource research in the developing world. These include the low level of present knowledge; the number of low-income people who depend on the resources; the urgent need for viable policy options for better resource management; the increasing value of the resources and the effects of rising prices on the resource poor; the potential for aquaculture to make a larger contribution to food security, but only provided it is environmentally sustainable; and the need to identify and intervene quickly to remediate the status of aquatic resources that are degraded because they are downstream from other social and environmental systems. Fisheries and aquaculture products represent the fifth largest agricultural commodity in the world. 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.

There is no easy formula for setting 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. Much of the research is not amenable to standard economic cost-benefit analysis, which is most suited to research in its fourth role. New methods of analysis are required. 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 emphasize aquaculture technology rather than fisheries (for example, see Davy 1993), probably since the impact of the former is usually clearer. This allocation occurs even though the majority of production still comes from capture fisheries, about which too little is yet known. Managers of fisheries and coastal resources therefore lack the information that would allow them to manage these resources sustainably.

It could be argued that returns from research are less certain in fisheries than in other fields. This uncertainty, however, is a result of the 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 insecurity.

Conclusion

A profound and dramatic 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 aware of the transition, but little has been done to anticipate or minimize its consequences. The future state of affairs is likely to be much different from the present.

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

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Meryl Williams is director general of the International Center for Living Aquatic Resources Management in Manila, the Philippines.