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millennium

# Biodiversity and Fisheries

# CHAPTER 1: SYNTHESIS REPORT

## A Primer for Planners

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# Part One - Opening Our Eyes to Aquatic Biodiversity

Compared to even a decade ago, awareness of the importance and precarious state of aquatic biodiversity is increasing. International meetings and resolutions continue to raise the profile of aquatic biodiversity, and the general public in many countries is now familiar with the effects of fisheries collapses and the strong likelihood of more to come. Few people, whether they are scientists, managers or lay people, would disagree that there is a fundamental problem with fisheries, namely that managing single species for maximum sustainable yield, as has been done in most places for the past fifty years, simply doesn't work –biologically or socially. The failures of this kind of management have been so spectacular and so costly that it seems safe to say that the first decade of the new millennium will feature intense debate, experimentation, increased collaboration (on all levels) and real progress in the way aquatic organisms are managed. Even the way fishing is studied by the scientific community is changing. A fresh look at the effects of historical overfishing, for example, using data sources that go beyond fishing records and include paleoecological, archaeological and historical archives, shows that the ecosystem effects of marine fishing are far more profound, and much older, than previously realized. [77]

## Aquatic biodiversity: not really a new issue

If aquatic biodiversity is beginning to attract the attention of agencies and policy makers, and if fisheries management is in ferment, does this mean that "managing for biodiversity" is a new problem? The answer is a resounding "No." Twenty-one years ago, the Food and Agriculture Organisation (FAO) of the United Nations and the United Nations Environment Programme (UNEP) convened an Expert Consultation on Conservation of the Genetic Resources of Fish, and their report [42] is instructive for anyone who thinks that international concern for aquatic biodiversity began in the late 1990s. To be sure, the experts who met in Rome framed their deliberations in terms of "genetic resources", but it must be remembered that the CBD itself is essentially a framework agreement on genetic resources, a term that connotes practical, economic value. The newer term "biodiversity," which describes the variability of all living things, simply expresses the concept of genetic resources in terms that are less user-oriented, more ecosystem-friendly, and more acceptable to people who see living things as having value beyond the purely economic.

Here is what the experts of 1980 saw and concluded:

- We need to adopt an ecosystem-wide outlook in conserving genetic resources (a recommendation that predates the ecosystem approach of the Convention on Biological Diversity).
- Preservation of habitat is the fundamental means of conserving ecosystems.
- Recommended the establishment of protected areas.
- Described the vulnerability of organisms in inland waters to habitat loss and pollution.

- Singled out introductions of exotic species as a particular impact on freshwater biodiversity.

- Noted the potential for cultured species to genetically overwhelm their wild relatives through captive breeding and enhancement.

- Recommended greatly increased training and awareness.

As readers of this report will learn, few of these prescriptions have changed in twenty years.

Although the focus of the Expert Consultation was genetic, their conclusions and recommendations are really no different from what the international biodiversity community is seeing now, and they will be echoed throughout the present report. Throughout the 1980s, papers continued to be written on conservation of fish genetic resources, pointing out the importance of minimum population sizes and identifying genetic diversity as a non-renewable resource. It began to be clear that too much emphasis on conservation of species could mask the loss of irreplaceable genetic variation in local populations, and various "conservation solutions," including expanded captive breeding programs and gene banks, began to appear. [101] Although the importance of fish genetic resources for aquaculture was frequently stressed during this period [125], the tone of the writing and discussion was that of conservation biology. [150] Biodiversity was not yet an issue.

If many of the fundamental ideas about aquatic biodiversity are "old", what has changed in the last twenty years that makes the present report important? Why is the "ecosystem approach to management" fashionable in 2001 when indigenous societies around the world have been practicing it for centuries? The following major developments are suggested as being responsible. Many of them are interlinked.

### The Convention on Biological Diversity

The Convention on Biological Diversity (CBD) was an unprecedented global accord that focused directly on genetic resources. Through its enabling mechanisms like the Clearing House and SBSTTA, and using newly created funding mechanisms like the Global Environment Facility, the CBD essentially gathered up all the concerns of experts like the FAO Consultation referred to earlier and recast them in the light of sovereignty (and to a certain extent the rights of local communities). To its harsher critics, the CBD was no more than a free trade agreement in genetic resources, but its great strength has been to provide a new vocabulary and some generally accepted rules for sustainable use and equitable sharing of biodiversity. The playing field itself continues to change shape, but the CBD provided a much-needed context and framework for concerns such as those of the 1981 Consultation.

### The roles and rights of local communities

The roles and rights of local communities in managing biodiversity have been recognized. The CBD played a major role in putting these rights on paper, and while the language of the convention mostly reflects experience with crop germplasm and agriculture, it clearly encompasses aquatic biodiversity too. Participation of local communities in management of their own fisheries grew throughout the past two decades and it is abundantly clear from many of the case studies in this report that some of the most promising approaches to using aquatic biodiversity sustainably have been developed by local communities, often as a direct reaction to ineffective "top-down" management (Coates, Alcala, MacKay, Ruffino, this volume). Aquatic biodiversity is now viewed in a social context, which makes it easier for society as a whole to get involved in ways that were never possible when the only concern seemed to be with the fish themselves.

### The media discovered fisheries

Catastrophic fisheries collapses like the disappearance of the Atlantic cod [76] or the eradication of some three hundred cichlid species in Lake Victoria [156] were not lost on the global media, who have learned to link these "biological" disasters to the human consequences in loss of livelihood. Fisheries mismanagement became a staple news item. Throughout the 1990s, for example, media from California to Alaska seemed preoccupied with declining salmon stocks and the political and social fallout, to the point where few people in the region could help but be aware of aquatic biodiversity..

### The NGO sector exploded

The 1992 Earth Summit that produced the CBD was the first global stage for environmental NGOs, which have rapidly grown in numbers and influence ever since. NGOs specifically dedicated to water and aquatic life are now capable of steering, or at least substantially deflecting, the global conservation agenda. NGOs range from local organizations dedicated to local issues, to international groups capable of altering business and political decisions, and they understand the use of media.[5] There are now many such organizations that exist solely to promote sustainable use of aquatic biodiversity.

### Climate change

Climate change has been identified as a pervasive influence on biodiversity, one that may over-ride attempts to restore habitat or reform fisheries management. To return to the example of Pacific salmon, the effects of ocean warming on ocean survival have entered the debate on management to the extent that the need to conserve biodiversity represented in genetic population structure–which may hold the key to adapting to the changes in environmental temperature– is even more apparent than it was twenty years ago.

### Societies and technologies have changed radically

Politically, globalization has drawn attention to such trans-boundary fishing concerns as distant water fleets and the impact of cultured exotic species, grown mainly for export, on local fish populations. The arrival of the Internet made possible the publication and exchange of vast amounts of information on aquatic genetic resources and fisheries. Fisheries management itself has benefited from technological development, with the older, blunter instruments of genetic analysis being replaced by DNA-based techniques that have revealed complexities of stock structure that are profoundly influencing the way people think about managing aquatic biodiversity.

Of all these changes, perhaps the most important, and the one that will be most evident from the Case Studies in this report, is the recognition of the social role of aquatic biodiversity. Saving biodiversity for its intrinsic value has been successful in the past, but generally only for charismatic mammalian species. Fish are neither charismatic nor cute, they are normally hidden, and they have few champions with public profiles high enough to galvanize public interest. Perhaps the greatest advance in aquatic biodiversity conservation has been recognizing the hidden army of advocates that fish *do* have, namely the people who depend on them for their livelihoods.

## Suggested development investments

### Small-scale fisheries as advocates for sustainability

Small-scale fisheries are a powerful inducement for conservation and sustainable use of aquatic biodiversity. Especially in freshwater habitats, fishing communities may be the best advocates for sustainable use: diverse fishery = diverse river. Their advocacy can be multiplied by giving them the tools to negotiate more effectively with the other sectors whose influence on habitat is likely more detrimental to aquatic biodiversity than is fishing. These tools are both technical (for example, better knowledge of catch and effort) and socio-political (for example, negotiating skills).

As the “hidden army” of advocates for fisheries sustainability, local communities will respond to any action that provides them with a voice in management. In communities where this ability to network and influence management needs to start from the ground up, a first step is investment in community fisheries awareness (school events, fish “days”, festivals).

*Relevant National Case Study: Mekong River (Coates).*

### Cross-sectoral networking

Because aquatic ecosystems are affected by so many human actions in addition to fishing, cross-sectoral linkages should be built into all fisheries development projects, either explicitly, through inclusion of other sectors, or through promoting local awareness of the project and its issues using media and schools

### Awareness and use of existing agreements

Awareness of the FAO Code of Conduct for Responsible Fisheries and the CBD should be promoted among managers of aquatic biodiversity. Communities in particular need to be aware of the leverage provided by the CBD. Linkages can be made with community organizations who have already “made the leap” and are using the CBD in their development plans.

### Local leaders

Efforts to introduce sustainable fisheries development need to identify and invest in strong local personalities. While fisheries development projects need to be participatory, a concerted effort should be made to identify and include local leaders, who need to be involved to ensure sustainability of project results. If participatory management is to work, the leaders who will ensure sustainability should not be foreign-trained or assisted technical and social scientists, but local community members. It is these people who must be involved. Local NGOs should also be empowered to promote fisheries management changes regionally and nationally, thus ensuring a network that reaches from community to state.

*Relevant National Case Study : Cook Islands and Fiji protected areas (MacKay); Projects IARA and Varzea, Amazon Basin (Ruffino); Philippines protected areas (Alcala).*

## Local awareness of effects of climate change

Climate change must be recognized as a new and powerful influence on aquatic biodiversity, and capacity needs to be built to make fishing communities in developing countries aware of its implications. Modeling studies are needed to create scenarios that can be discussed in communities and with managers, who need to realize that fisheries "good times" may not last. Species that depend on transient floodplains for reproduction and rearing, such as tropical migratory species, may experience a severe reduction of habitat and are at special risk. These species are critical providers for local communities but occur in regions where they are unlikely to be studied in depth.

## Involving communities in biological studies

Local riverine fishing communities can become participants in biological studies needed to improve management of stocks. The genetic information we already have on fished species is only the tip of the iceberg. Regional laboratories are gaining expertise in DNA analysis and can form partnerships with communities for sample gathering. Training is needed in sample collection and handling for a variety of other kinds of studies as well, including studies of life history and other biological characteristics. Participation in sampling programs encourages linkages between communities, scientists and managers, and opens eyes in both directions.

## Key bibliographic resources

FAO. 1981. **Conservation of the genetic resources of fish: problems and recommendations.** [42]

FAO. 1993. **Report of the expert consultation on utilization and conservation of aquatic genetic resources.** [43]

Harvey, B, C. Ross, D. Greer, and J. Carolsfeld (Eds.). 1998. **Action before extinction: an international conference on conservation of fish genetic resources.** [63]

Pullin, R. S. V., D. M. Bartley, and J. Kooiman (Eds.). 1999. **Towards policies for conservation and sustainable use of aquatic genetic resources.** [127]

These four conference proceedings chart twenty years' growth in international awareness of the importance of aquatic biological diversity. They provide the groundwork for development of policy at the national and international level and provide a degree of regional coverage of aquatic biodiversity issues.

FAO. 1995. **Code of conduct for responsible fisheries.** [44]

The Code is a pivotal document. Article Seven (Fisheries Management) provides the underpinning for fisheries that are managed to preserve biodiversity, and is supported by a subsequent series of FAO handbooks, the FAO Technical Guidelines for Responsible Fisheries.

Anon. 1999. **The non-governmental order: will NGOs democratise, or merely disrupt, global governance?** [5]

A thoughtful analysis of the influence exerted by NGOs on national and international policy.

# Part Two - Global Aquatic Biodiversity and its Status

There are several definitions of the term "biological diversity" (often shortened to "biodiversity"), which remains a source of confusion for some. The CBD defines biological diversity as "the variability among living organisms from all sources" (Article 2). Most generally, it has been defined as "the degree of nature's variety" [100], or "the variety of life and its processes". [72] The concept of biodiversity embraces all species of plants, animals, and microorganisms, and their ecosystems. The biologist and writer Edward O. Wilson calls biodiversity the "key to the maintenance of the world as we know it". [173]

Biological diversity is generally accepted to occur at different levels: *genetic diversity* (lots of different gene combinations for each species); *species diversity* (lots of different species for each habitat); and *ecosystem diversity* (lots of different habitats). It would be fair to say that the present evolution of fisheries management is toward greater consideration of the genetic and ecosystem aspects of biodiversity.

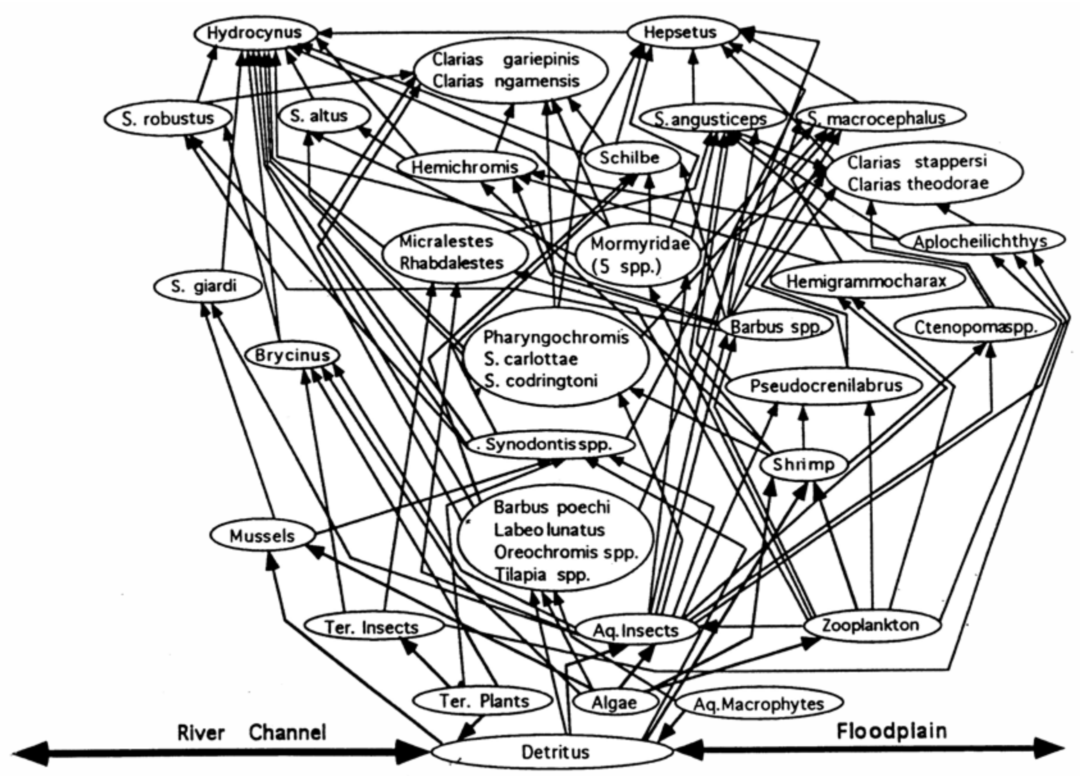
## Aquatic biodiversity

Statistics on global water are well known: 97.5% is marine, and only a tiny fraction of fresh waters is available on the surface of the globe to support life. [97] Fresh water makes up less than 0.5% of water on the planet, so freshwater habitats are precious. Although inland waters represent a vanishing small proportion of the earth's total water, they contain an astonishing 40% of all aquatic species. In other words, on an area basis, the vaunted richness of aquatic life in coral reefs is, in fact, far surpassed by many tropical rivers, a source of frustration for biologists of inland waters trying to promote sustainable use of biodiversity (Coates, this volume)..

Although there are many more species on land than in water [95], more than half of all vertebrates are fishes, and the higher level diversity of the major groups (phyla) of organisms is greater in aquatic environments. This high diversity has led some biologists to wonder why the bulk of conservation effort has gone into terrestrial ecosystems, and it is certainly true that because fish are very diverse and inaccessible, we know less about their conservation status than for any other vertebrate group. The short answer, of course, is that what lives in water is seldom seen, hard to study, and hard to monitor for changes [80]. Other reasons include vast aquatic areas that are not "owned" by any one nation (leading to squabbles over migratory species); the non-cuddly nature of aquatic creatures; and their fundamental association with basic human survival that makes "conservation-oriented" management decisions more difficult to defend. [138]

Yet the complexity of aquatic ecosystems is staggering. Figure 1 represents the food web for the Upper Zambezi River, and shows how organisms interact not only functionally (through chains of production and consumption) but also geographically and seasonally as the floodplains fill and empty. Harvesting a half dozen fish species from such a complex system is like reaching into a tangle of phone cables and blindly pulling out a handful of wires: the implications are hard to measure, and impossible to predict. Ryman *et al.* [138] describe most fisheries as "killing first and then deciding what to keep," analogous to hunting mammals or birds by bombing their habitats (as, for example, in the dynamite fishing of coral reefs).

**Figure 1: Fishes as functional components of the Upper Zambezi River floodplain food web.** [174]



In the face of such complexity, all authors on aquatic biodiversity have to make choices, and this report is no different. Here the emphasis is practical and social: aquatic biodiversity is considered for its importance in fisheries. Nevertheless, if there is one enduring image the reader takes away from this report it should be of the Zambezi food web, because extraction of a single member of an aquatic ecosystem for food is never without consequences to the whole.

## A growing appreciation of aquatic biodiversity at the genetic level

With the number of formally described marine and freshwater fish species currently around 25,000 and still climbing [110], there is clearly very high biological diversity at both the species and ecosystem levels. At the genetic level, local populations of freshwater fishes have generally been believed to be more divergent than marine, with local, genetically unique populations of the same species more common in fresh waters. Pacific salmon species, for example, can be subdivided into subpopulations that are genetically and geographically distinct enough to avoid interbreeding most of the time, while herring populations, if they exist at all, are fewer and more broadly distributed. [138]

Because fish are the only major food source still harvested from wild populations [138], knowledge about the genetic structure of those populations is imperative for resource management. However, the book on fish genetic population structure remains largely unwritten. The availability of finer analytical tools for determining population genetic structure, such as the DNA methods referred to earlier, is forcing constant revision of sweeping statements about the homogeneity of stocks. Cold water species are being intensively studied with a view to rationalizing management (see for example [8]), and the genetic structure of tropical freshwater fish populations has begun to be looked at as local laboratories get access to new technology. Genetic information on fish is pouring out of laboratories: the number of publications in the scientific literature on fish and fisheries that contain the descriptor "DNA" has tripled since 1987. [128] At this point all we can say with certainty is that molecular genetics serves to demonstrate the continuum of genetic differentiation from population to species [24], and that the genetic information we already have is only the tip of the iceberg. It is also important to realize that knowledge of genetic fine structure cannot stand alone for management purposes, and generally needs to be complemented by life history and other biological characteristics (see for example [136]). As more of the genetic fine structure of fish populations reveals itself, the task of managing for diversity will become even more complex.

## Marine and freshwater biodiversity: some important differences

### Oceans

Oceans cover 71% of the world's surface, but life within them is unevenly distributed. Marine biodiversity includes not only fishes but also a huge variety of invertebrates (many of which are heavily fished), as well as plants and microscopic life. Biodiversity is distributed throughout the oceans, although most of it is harvested along coastal zones and the continental shelf. The shallow continental shelf extends up to two hundred kilometres from land and forms less than ten per cent of the total ocean area, but it is the most intensively studied. The Large Marine Ecosystems from which most of the world's marine fish are harvested are found on the continental shelf. [169]

Broadly speaking, marine fishes are either pelagic (open water) or bottom living. Mangroves and coral reefs are some of the best-known and most productive marine habitats, with very high numbers of fish species (for example, coral reefs in the Philippines and the Great Barrier Reef in Australia have at least 1,500 described species). There is also great diversity in seagrass beds, kelp forests, ocean trenches, and hydrothermal vents. Population increases and the resulting development, agriculture and agriculture are quickly reducing coral reefs, mangroves, seagrass areas and coastal wetlands. Over half of the world's mangrove forests, for example, have been destroyed. [84] Many of the more inaccessible mangrove areas of are little explored. [169]

### Freshwater biodiversity

Inland aquatic biodiversity is found in lakes, rivers, and wetlands whose size varies from a metre-wide creek to tropical rivers many kilometres across and home to countless undescribed species. All inland aquatic habitats are essentially coastal and share a high vulnerability to man-made disturbances.

Distribution of each kind of habitat is far from uniform. Brazil, for example, has few natural lakes but an unusually high volume of flowing water. Man-made reservoirs, especially in countries with large hydroelectric development, have created significant fisheries but pose major management problems related to maintaining biodiversity (see [141] for a discussion of fisheries in Lake Kariba, one of the world's largest man-made lakes, and *Agostinho and Gomes*, this volume). The boundaries of many rivers change dramatically with season, so that management of biodiversity must take into account shifting relationships with the surrounding terrestrial habitat. The most extreme example of this is the great tropical rivers of Asia, Africa and South America, in which whole species assemblages have evolved to exploit periodic inundation of the floodplains (see *Coates, Ruffino and Agostinho and Gomes*, this volume). Many large rivers traverse several countries, which lends an extra political dimension to management, especially when damage caused in one country has a downstream effect in another.

Marine and freshwater biodiversity are so dissimilar that it is rarely useful, from a management perspective, to speak of "aquatic biodiversity" as a single subject. The lower number of subpopulations in marine environments, for example, probably reflects the fact that there are fewer geographical barriers in the ocean. Freshwater systems are "captive," usually bounded by landscape features that profoundly limit the ability of freshwater organisms to escape the effects of habitat disturbances. Geographic boundaries often mean that population sizes are smaller in fresh waters (because they are confined or isolated), and they are more vulnerable. As we will see later, the widespread distribution of many marine populations is what makes protected areas so attractive as management tools, because a strategically placed protected area can "seed" a much larger area with young fish.

The threats to biodiversity in marine and freshwater systems also differ in significant ways. Fishing is a far more significant negative impact on marine systems than in inland waters, where habitat loss and pollution are more important, but the end result is still that freshwater species are at greater risk of extinction than marine. Eighty-four percent of fish species in the IUCN Red List are freshwater. Globally, the accepted estimate for the number of threatened, endangered or extinct freshwater species is 20 percent, rising to much higher proportions in some places - 33% in Australia, for example, and 42% in Europe. [162] The World Conservation Monitoring Centre prepared an "inland water biodiversity index" based on available population data for 70 species, and showed a decline of around 50 percent from a 1970 baseline. [170] There are many examples of drastic reductions of freshwater biodiversity, through extirpation of species (such as the disappearance of many chichlid species from Lake Victoria) or removal of genetically distinct populations (such as the disappearance of wild Atlantic salmon from more than three hundred river systems in North America and Europe [179]). In the southwestern United States, there has been a 125% increase in number of jeopardized fish species in the past twenty years. [166]

## Services provided by aquatic biodiversity

The Earth has a renewable but finite supply of water, which ebbs and flows in a grand cycle inseparable from life on the planet. As the human population grows, so do its demands for water for agriculture, industry and domestic consumption. Increased population pressure affects the water supply in many ways, from changing its flow to degrading its quality – both of which are critical for the maintenance of aquatic life. Looming over all is the spectre of climate change, which through alteration of global temperatures is affecting the movement, availability, and even the temperature of water in ways that were not even conceived of two decades ago.

The importance of aquatic biodiversity to humans is inseparable from the importance of the waters themselves. Freshwaters provide moving water for transport of people and goods, water for irrigation and drinking, waste disposal, and a source of hydroelectric energy as well as recreational and cultural benefits. The biological diversity within those waters primarily provides food, but it also supplies the ornamental fish trade as well as plants and animals for medicinal use. In terms of goods and services, inland waters contribute more to global economies than all terrestrial ecosystems combined, including forests, grasslands and rangelands. [36] The oceans, while not (yet) providing drinking water or energy, are not only the source of most of the world's food fish, they also produce a cornucopia of animal and plant life with huge potential for medicinal and ornamental use. Unfortunately, they also provide a vast waste disposal "bucket" for land-based pollution.

The removal of freshwater organisms as food is currently estimated at 12% of all fish caught, a figure that does not include farmed fish and that probably represents less than half the actual harvest due to the informal nature of many inland fisheries. [34] Freshwater aquaculture produces more than twice the tonnage of fish harvested from the wild [49], and has its own complicated effects on biodiversity.

### Ecosystem services

Despite the rapidly growing literature on economic valuation of biodiversity, it would be foolish and shortsighted to value aquatic biodiversity solely for its contribution to human diets and economies. After all, global fisheries concentrate on a tiny fraction of the 25,000 known fish species. Marine fisheries, for example, depend primarily on about 200 species. In Africa, the majority of freshwater landings are of a single species, the Nile perch. [49] What "value" do the other 24,800 species have?

One way to answer this question is to consider the "ecosystem services" performed by fish. Again, the Zambezi food web (Figure 1) is instructive. Clearly, the indirect effects of fishing, by removal of unwanted species (by-catch) or alteration of ecosystems by fishing practices like bottom trawling, are just as important as the removal of the target fish. If we can identify some of the other roles played by fish, in addition to feeding us, we will be taking the first step toward managing fish populations in a holistic way.

Some of the ecosystem services generated by fish include the following (adapted from [71]):

- Regulating food web dynamics. See, for example the explosion of Baltic herring after its chief predator, cod, was reduced by overfishing [153], or the linked collapses of the capelin and cod fisheries in the Barents Sea. [60]

- Regulating sediment processes, for example the spawning activities of salmon that maintain stream contours and stir up food for other organisms. [103]

- Regulating carbon supply.

Acting as links between ecosystems, for example the role of salmon in transporting marine-derived nutrients far inland, and the importance of these nutrients for predators, juvenile fish, and forest vegetation. [15] [30] In tropical rivers, migratory fish often travel more than a thousand kilometres to spawn, traveling between river and floodplain, and frugivorous (fruit-eating) species distribute the seeds of fruit trees over large areas [58] [57].

Declines in aquatic biodiversity can thus have far-reaching consequences. When sockeye salmon failed to return to Rivers Inlet, British Columbia, in 2000, not only did people lose their livelihoods but their gardens began to receive visits from starving grizzly bears. In this case, the consequences of poor management and climate change were unexpected, especially to the bears, many of which had to be shot. The persistent historical overfishing of large marine mammals and fish has recently been shown to profoundly affect marine ecosystems, and to have done so long before the effects of pollution, habitat destruction, introductions of exotic species, and even human-caused climate change. [77]

Biodiversity, especially at the subpopulation level, also provides a “hedge” against changes in the conditions under which a species lives. Genetic variability provides a range of options that helps species survive. Pacific salmon are good examples, with very high intra-specific genetic variability. Populations vary in characteristics such as run timing and temperature preference, and it is this variability that ensures that some populations can survive environmental changes. Selectively eliminating some of these populations, as happens through many fisheries, can eliminate adaptations the species as a whole may need to survive.

## How do we describe the “health” of aquatic biodiversity?

A number of excellent recent compendia attempt to describe aquatic biodiversity and its status geographically. [47] [46] [47] [97] [113] [131] [169] [170] [162] Many identify areas of high endemism[1] . Coral reefs are usually singled out as examples of high marine biodiversity, with 93,000 species so far identified. [129] The high number of fish species in the Amazon River (3,000 is often cited) is frequently advanced as the preeminent example of freshwater biodiversity, although Coates (this volume) points out that fish species diversity of the Mekong River, per unit area of catchment, is roughly three times that found in the Amazon River basin, even though the number of species in the Mekong is lower.

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[1] an endemic species is one that occurs in one place only, so high endemism makes an area’s biodiversity less easy to replace.

While many surveys attempt to identify "hot spots" of aquatic biodiversity (e.g. [113] for Latin America or [131] for freshwater systems in general), these tend to be in terms of number of species. As our knowledge of population-level genetic structure increases, and as we understand more about interactions between species, such listings may have less meaning. Those charged with promoting or investing in the sustainable use of aquatic biodiversity should also be aware that what we know about aquatic biodiversity now is the tip of the iceberg, and that new levels of complexity – and new "hotspots"–are likely to be revealed. A recent list of global hotspots of freshwater biodiversity, for example, lists only two regions in South America, and does not include the Amazon basin. [113] This is a sampling artifact: the listing requires known richness in more than one group of aquatic animals, from a list that includes fishes, molluscs, crabs, crayfish and shrimp. If not enough is known on all these groups, even the Amazon will not be included.

## Lists of threatened species

Lists of endangered and threatened species, although imperfect, reflect the continuing debate on how to assess risk, how to set reference points for action, and how to define what to conserve. [124] The lists also reveal some interesting things. Of all the fish classified as threatened in the 1996 IUCN Red List, for example, 84% are freshwater species. [97] It is clearly more difficult to extirpate a marine fish species than an inland one.

Decision-makers also need to be cautious when considering lists of species at risk, the IUCN Red List being the one most frequently cited. Such lists are undeniably important, and we use the IUCN listing in this report as a rough indication of numbers of species at risk, but it must be remembered that the Red List is also an indication of how much effort has gone into sampling, and that the number of fish contained is probably a gross underestimate. [21] Like crime statistics that can actually increase as certain crimes are better reported, the numbers of threatened and endangered species reflect the effort gone into looking for them. Parts of the world where there are more resources for study and evaluation, such as the United States, tend to be over-represented in lists of endangered species. Southern Africa is a hot spot for endangered freshwater fishes primarily because the area has outstanding expertise in ichthyology. [175] Economic development agencies could offset the emphasis on global biodiversity hotspots by also considering the social importance of aquatic biodiversity in different locations. Reliance on high aquatic biodiversity for subsistence may, for example, tip the balance for investment in research and training.

## Fisheries landings as indicators of species status

Despite difficulties of sampling and gaps in our knowledge, it is possible to make some general statements about the status of marine and freshwater biodiversity. The relatively low numbers of threatened and endangered marine fish species (at least in comparison to freshwater species) reflects their basic resilience and wide geographic distribution. It is difficult to completely wipe out a marine fish species, but relatively easy to reduce its numbers so much that any fishery becomes unsustainable and communities are affected. This can be done by overfishing, for example the Atlantic cod, or by other means such as introduction of competing exotic species, as in the freshwater example of Lake Victoria. If reduction of the species is through habitat loss or pollution or introduced species, it is more difficult to reverse the trend. For all these reasons, the best indicator of the overall status of global marine biodiversity is probably *fisheries landings*.

The overall ocean fishing regime today is characterized by declining sizes of fish caught and excessive by-catch (discards). World harvest is still increasing, but the rate of increase has declined. Around 60% of the main world fisheries resources are mature (at their peak) or senescent (declining), and are thus in need of urgent management action. [47] Fisheries in the Northwest, Southeast and Eastern Central Atlantic peaked one to two decades ago and are now declining. [50] More telling than declines and collapses, in terms of biodiversity, is the phenomenon of “fishing down the food web”. Larger fish at the top of the food chain are being depleted and replaced by fisheries for smaller fish at a lower trophic level. This trend, which is now reported globally, clearly shows that, while overall catches may in fact still be increasing, marine food webs (=biodiversity) are being profoundly altered. [117] [120]

The spectacular declines in abundance associated with well-known fishery collapses have stimulated much research and discussion about the likelihood of actual extinction of marine species. From a policy standpoint this question is very important, because legislation that protects endangered species must contain decision points based on population sizes and changes. [124] The suggestion that marine fishes are less vulnerable to extinction than other taxa (see, for example [109]) is at the centre of considerable debate. First, the existence of sub-species stock structure at the genetic level means that considerable biodiversity can be lost before a species goes extinct. Second, the ability of marine fish to recover following severe population reductions is limited by complicating factors like climate and ecosystem change. Exempting marine fishes from population-decline criteria used to assign extinction risk is therefore inconsistent with the precautionary approach. [75]

Inland fisheries are much more poorly documented than marine, and knowledge of the diversity and status of inland fish species has been concentrated in the academic community – one of the reasons the general interest in conservation has not, so far, spread to freshwater animals. Many countries do not collect adequate statistics on harvest, so it is not as easy to gauge the health of aquatic biodiversity by examining records of landings as it is for marine species. However, fishing is not the primary impact on inland water biodiversity, and the confined nature of rivers means that the effects of other man-made disturbances like habitat loss and pollution are readily apparent in species extinctions.

## Suggested development investments

### Profiling freshwater biodiversity

The contribution of inland waters to the global economy is under-appreciated. Inland waters contain 40% of all aquatic species, are subject to greater habitat threats than the oceans, and have by far the largest proportion of endangered and threatened species. Inland aquatic biodiversity can be expected to be lost at an accelerating rate, and freshwater species are more vulnerable to losing biodiversity at the genetic level than are marine.

Inland water fisheries are mostly small-scale and play a larger role in supporting communities in developing countries than do marine fisheries. However, inland fisheries are poorly documented, and detailed knowledge of freshwater species is still concentrated in universities. Increased investments need to be made in identifying and managing freshwater aquatic biodiversity in developing countries. Special attention should be paid to tropical floodplain fisheries in South America and Asia, including collection of better harvest statistics (which can be used to gauge the health of fisheries and biodiversity).

*Relevant National Case Studies: Mekong River (Coates); Papua New Guinea (Swales); Parana River (Agostinho and Gomes); Amazon River (Ruffino).*

### Knowing species better

Aquatic biodiversity is under-represented in species lists and global conservation priorities. Traditional knowledge and scientific surveys both need support and harmonization to underpin sustainable management. Local community leverage in management negotiations is much improved by knowing distribution, occurrence and status of their species.

### Social importance of biodiversity vs. hotspots

Biodiversity funding is often guided by so-called “hotspots.” A more development-oriented index (a Biodiversity-Livelihood Index?) might take into account not only the number of aquatic species but also the number of people dependent on them and their incomes. Investment in innovative alternative rankings of geographic areas could help in setting priorities for limited funds. Reliance on high aquatic biodiversity for subsistence may, for example, tip the balance for investment in research and training in a particular location.

*Relevant National Case Study: Mekong River (Coates).*

## Key bibliographic resources

Bruton, M. N. 1995. **Have fishes had their chips? The dilemma of threatened fishes**. [21]

Discusses extinctions and threats.

Cambray, J. A. 2000. **‘Threatened fishes of the world’ series, an update.** [23]

Handy compilation of fish species at risk of extinction (although all such lists must be viewed as reflecting research effort).

Cederholm *et al.* 2000. **Pacific salmon and wildlife: ecological contexts, relationships, and implications for management.** [30]

Substantial report on the ecosystem role played by Pacific salmon; excellent example of ecosystem approach.

Costanza *et al.* 1997. **The value of the world's ecosystem services and natural capital.** [36]

A landmark paper that renewed interest in placing an economic value on biodiversity.

McAllister, D. E., A. L. Hamilton, and B. Harvey. 1997. **Global freshwater biodiversity: striving for the integrity of freshwater ecosystems.** [97]

Exhaustive review of freshwater biodiversity occurrence and impacts.

Nelson, J. S. 1994. **Fishes of the World, 3rd edition.**

The standard reference on fish taxonomy and diversity.

FAO**.** 1999. **Review of the state of world fishery resources: inland fisheries.** [49]

Detailed fisheries-oriented review, substantially included in the FAO's "State of World Fisheries and Aquaculture", published semi-annually.

Holmlund, C. M., and M. Hammer. 1999. **Ecosystem services generated by fish populations.** [71]

Describes the roles fish play in addition to being food for people.

**IUCN Red List** (www.iucn.org/redlist/2000/index.html).

The most- cited list of threatened and endangered species.

Olson *et al.* (Eds.). 1998. **Freshwater biodiversity of Latin America and the Caribbean: a conservation assessment.** [113]

Results of a workshop that considered rapid analyses of freshwater biodiversity status. Excellent maps; lists of areas of conservation concern.

Pauly *et al.* 1998. **Fishing down marine food webs.** [120]

First description of the phenomenon of "trophic mining" in fisheries.

Pauly *et al.* 2001a. **Down with fisheries, up with aquaculture? Implications of global trends in the mean trophic levels of fish.** [119]

Though-provoking analysis of the effects of aquaculture as a supplier and consumer of aquatic protein.

Revenga et al. 2000. **Pilot analysis of global ecosystems: freshwater systems.** [131]

Comprehensive overview of freshwater biodiversity; not limited to fisheries.

Ryman, N., F. Utter, and L. Laikre. 1995. **Protection of intraspecific biodiversity of exploited fishes**. [138]

An authoritative, thoughtful and very readable review of the genetic structure of marine and freshwater fish populations and how it is affected by fisheries, pollution and habitat alteration.

WCMC (World Conservation Monitoring Centre). 1996. **The diversity of the seas: a regional approach.** [169]

Sourcebook on marine biodiversity: occurrence, impacts and status.

WCMC (World Conservation Monitoring Centre). 1998. **Freshwater biodiversity: a preliminary global assessment.** [170]

Sourcebook on freshwater biodiversity: occurrence, impacts and status.

Wilson, E. O. 1992. **The diversity of life**. [173]

A far-reaching and readable treatise on biodiversity, written for the lay person by one of the world's foremost authorities.

# Part Three - Impacts on Aquatic Biodiversity

The study of aquatic biodiversity is a classic example of the "shifting baseline" syndrome. Changes are difficult to detect because there is no solid starting point against which to gauge them. Fisheries managers routinely begin their careers assuming the present condition of the ecosystem as a baseline, whereas of course that baseline shifts with each generation – generally downward. [115] Recent research on the ecosystem effects of overfishing suggests that the shifting baseline syndrome is even greater than commonly believed, and that the historical abundances of large marine mammals and some invertebrates are inconceivable to modern biologists and managers. [77] In developing countries especially, information on aquatic biodiversity, where it exists, is sparse and scattered and cannot be used practically in management. Although investment in development should never lose sight of the connection between biodiversity and people, meaningful programs can only be developed when time and money have been spent on research and monitoring.

Most of the major impacts on aquatic biodiversity interact, which is one of the main reasons why the sustainable management of aquatic biodiversity demands new systems of governance. [28] Because the causes of decline of fish species are multiple, cumulative, and long-term, reversing those declines will require a completely different frame of reference on the part of resource managers, who will need a mandate from society to deal with all the sources of negative impacts, not just fishing.

Rates of extinction for aquatic species appear to be higher than for terrestrial ones. Approximately 4 percent of North American freshwater species are expected to be lost each decade, nearly five times the rate for terrestrial species. [132] Estimates like these, qualified though they are by availability of data and an emphasis on countries where research and reporting are greatest, are enough to place the health of freshwater biodiversity at the bottom of the geographic list, below that for coastal regions, forests, grasslands and agriculture. [162] If we refer back to the Zambezi food web and contemplate the effect of removing a fish species or two, it is not difficult to imagine the cascade effect of extinction on ecosystems. And because the majority of fisheries in inland waters are small-scale, the social impact of biodiversity loss will be great.

The impacts on marine and freshwater systems are similar but their relative importance differs. Fishing, for example, is the single most important impact on marine biodiversity, whereas freshwater biodiversity is much more affected by loss of habitat (as one would expect given the "captive" nature of freshwater ecosystems and the high concentration of people around lakes and rivers). In general, more attention is paid to biodiversity in marine waters than freshwater. [4] However, aquaculture (and other negative impacts) affects freshwater systems more than it does marine – partly because escaped exotic species flourish more easily in fresh waters, but also because most of the world's aquaculture is in fresh water. [157] It is still too early to say whether the effects of climate change will be greater in the oceans or inland; alarming scenarios have been drawn for both.

The time scale of impacts on marine and freshwaters is also different. Human populations tend to spread inland, colonizing areas farther away from coastal regions and putting increasing pressure on inland aquatic habitats. The contamination and destruction of inland watersheds accelerates as people occupy continental interiors, and inland aquatic biodiversity can be expected to be lost at an accelerating rate.

## Impacts of fishing on aquatic biodiversity

Fish are the only major food source still harvested from wild populations. [138] Total world fish production is still rising, although the rate of increase is much greater for aquaculture than it is for capture fisheries, where 44% of marine fisheries are already fully exploited. Aquaculture now provides 29% of global food fish production. [49]

Fisheries absorb 8 percent of global primary productivity – the sum total of life processes that result in billions of tons of biomass every year. [116] In contrast to terrestrial ecosystems where undisturbed areas still exist, most of the fishable areas have already been fished, so that expansion can only come from shifting harvest to lower trophic levels. [2]

It is difficult to generalize about the effects of fishing on aquatic biodiversity. "Fishing" encompasses an enormous range of operations in many different settings, from a group of families living off a few species of fish in a tropical river to a fleet of factory trawlers in the North Pacific. In some cases, the two extremes collide, as small-scale subsistence fishing runs head-on into competition from much larger operations for the same resources. Pacific salmon, for example, have traditionally provided food for aboriginal families on the west coast of North America through small-scale terminal (river) fisheries. Large-scale mixed-stock fisheries in the approaches to rivers have indiscriminately reduced the numbers of fish in smaller populations and reduced the numbers available for terminal harvest. In this case, there are effects of industrial fishing on biodiversity and on people (social equity).

It is also important to realize that fish populations fluctuate naturally. Changes in abundance that could be interpreted as stock "crashes" are surprisingly common, and may be entirely unrelated to fishing or habitat alteration. [67] The California sardine fishery, for example, has collapsed and recovered regularly over the past thousand years. [152] Environmental change is a likely cause of such crashes. Where crashes have profound social as well as biological consequences, it is sometimes difficult, and controversial, to separate the man-made causes from the natural ones.

Large-scale fisheries tend to be indiscriminate, an obvious effect on biodiversity. The enormous by-catch posted by marine fisheries (fully a quarter of reported annual production [49]) clearly has profound affects on non-target species, but most fisheries, even those without a large by-catch like the mixed-stock fishery on salmon, where salmon from different spawning rivers are caught together as they return from the sea, are inherently "messy" simply because fish are hard to see. [138] Local populations of freshwater fishes tend to be more genetically divergent than marine species, probably because there are fewer geographic boundaries in the marine environment and gene flow is consequently greater. Complex population structure, now revealing itself as DNA techniques are applied to more species

(Coates, this volume; Wood, this volume), means that freshwater species are more vulnerable to losing biodiversity at the genetic level.

Even recreational fisheries can affect biodiversity. There is a global trend toward the replacement of commercial harvest by recreational harvest on the same species. Pacific and Atlantic salmon, or several migratory species in Brazil, for example, are seeing an increase in recreational harvest and a consequent shift in the demographics of the people that benefit from them. However, recreational fisheries are not necessarily benign. Stocking with desirable game fish is widespread, and can have considerable impacts on ecosystems. Many small lakes in western North America, for example, have few fish species -a single salmonid species, for example (the recreational target) - and one or two prey species. There is thus no ecological buffering, and intensive sport fisheries can rapidly deplete the target species. [137]

## Genetic and ecosystem effects of fishing

Fishing can have profound effects at two levels of biodiversity, namely genetic and ecosystem. We have already seen an example of a genetic effect, on different populations of Pacific salmon in a mixed stock fishery. Even where complex stock structure has not yet been demonstrated, or where the contribution of various spawning populations to overall species survival has not yet been studied, the precautionary principle dictates that population subunits should be assumed to be discrete, and should be conserved through specific management measures. [155] Ecosystem effects have also been described, such as the removal of a predator or the interference with food webs. Fishing not only removes un-utilized fish species, it also affects ecosystems by removing other animals, like turtles, seabirds and marine mammals, or by damaging the sea floor and interrupting key ecological processes. [38] [6]

Research on the genetic effects of fishing has been mostly on anadromous species (those that migrate from the ocean to spawn in fresh waters), or marine species. Bearing in mind that populations of marine species are less genetically differentiated than freshwater species, the main genetic changes from fishing are through selection. Selection results because fishing is not random, and singles out certain ages and sizes. For example, heavily exploited fisheries often show a decline in the age or size at sexual maturity, a cumulative selection effect. [146] When fishing removes the larger animals from a breeding population it selects for smaller, slower-growing individuals as parents for the next generation. Gradually, the genetic makeup shifts. [121] Fishing that concentrates on spawning populations has also been shown to remove the oldest and most genetically variable (heterozygous) individuals. [147] Loss of genetic variability can also have direct effects on economic production. Population size alone is no guarantee of production. There is, for example, a link between genetic variability and the level of exploitable production in Alaskan pink salmon, because only a small proportion of the breeding population is the most productive in each generation.

Because fisheries exist to support people it is unusual for them to have an effect at the species level – that is, to result in the actual extirpation of a species. The point at which fishing becomes uneconomical is usually above the fail-safe point for survival of a species. In other words, people stop fishing on a species when it’s no longer worth the effort, and this point is usually before the species disappears.

It would be highly misleading to judge the effects of fishing on biodiversity solely by monitoring world fisheries productivity. As we have already seen, fisheries production continues to increase, and nations frequently use total aggregate landings as justification for continued fisheries expansion. However, the number of senescent fisheries (those declining in productivity) is on the increase, and overall productivity is maintained only by expanding to other areas and species. Typically, the direction of expansion has been toward lower trophic levels and smaller, younger fish. [117] [120]

The persistence of the effects of fishing on biodiversity is also sobering. Although marine fisheries in particular are often assumed to be able to recover more rapidly than freshwater fisheries [109] many species, especially cod and flatfish, show little if any recovery even fifteen years after severe reductions in reproductive biomass. [74]

## Overfishing

Overfishing can result from greed or from poverty. Sophisticated factory fleets can decimate fish populations, but so can hungry people. Overfishing is the main cause of aquatic biodiversity loss in the marine environment, but it also occurs in inland waters. Marine overfishing is possible partly because of over-capacity in the fishing fleet, which produces an uneconomic enterprise that is also a damaging one. Recent research shows that the ecological effects of overfishing in fact predate all other forms of human disturbance to coastal ecosystems, including pollution, decline in water quality and climate change. [77]

Eighty-five percent of fish products originate in the waters of developing nations, a distribution made possible not only by increased local fishing capacity but also by the existence of distant water fleets (DWF). These large and heavily capitalized fleets are capable of overfishing on a grand scale and play an important role in the decline of marine biodiversity. By definition they operate outside their own exclusive economic zones, although they are intrinsically no more likely to cause overfishing than national fleets operating within their own jurisdictions. Both kinds of fleet are prone to overcapacity and excessive effort. [17] The adoption of exclusive economic zones has changed the operation of distant water fleets in what are now national waters, but their ability to contest fisheries, and to over-fish, in the vast areas of the ocean that are open-access remains unchanged. The biggest distant water fleets are in former Soviet-bloc nations and Japan.

The classic recent example of overfishing, and one that involves distant water fishing nations, is the collapse of the Newfoundland cod fishery (the following account relies on. [17] Total landings of Northern cod tripled between the 1950s and late 1960s. By the time the international 200-mile fishing limit was declared in 1977, the cod were already near commercial extinction; that is, they weren't worth fishing for any more. [76] 1,398 trawlers fishing in the northwest Atlantic gathered the historic high of over 800,000 tons. Up to about 1960, most of the fish taken off the coast of Newfoundland were harvested by a small-boat inshore fishery, which was not capable of putting pressure on the stocks. It was the large trawlers, owned by European nations, that decimated the fishery, so that by the time Canada took over management in 1977 the damage was done. By 1992, the resource was clearly exhausted, and a moratorium was placed on fishing, with severe economic effects on Newfoundlanders. Northern cod have yet to recover. Clearly this is one case where a sustainable local fishery not only could not coexist with an industrialized fleet, it couldn't even continue to exist once the larger fleet had left.

## Kinds of overfishing

Technical progress, lags in available scientific information, and strong markets lead to over-exploitation. [62] Traditional concepts of overfishing arise from single-species population dynamics and stock assessment. They reflect the view that single species can be managed in isolation from their relation to other species within their ecosystem. For example, when the theory of maximum sustainable yield (MSY) becomes dysfunctional in practice, the result is *growth overfishing* (when animals are harvested at a size too small for producing the maximum offspring) or *recruitment overfishing* (when the adult population is fished so heavily it does not have the reproductive capacity to replenish itself). Growth overfishing is a precursor to recruitment overfishing, which can lead to stock collapse.

If, however, fisheries management is to consider not just single species models but entire assemblages of species and their trophic interactions, concepts and definitions of overfishing must change to include effects on ecosystems. One way to begin this process is to consider the characteristics of ecosystems that are important when devising fishing strategies that conserve them. These characteristics include (adapted from [107]):

- Technical interactions between species (by-catch),
- Biological interactions between species (predation; density dependence),
- Climate effects,
- Geographic range of species and density patterns,
- Time scale (seasonal, annual and decadal cycles).

A new category of overfishing, "ecosystem overfishing," could be defined as occurring when the following symptoms are evident: reduction in diversity; reduction in aggregate production of exploitable resources, decline in mean trophic level ("fishing down the food chain"; [117]), increased proportion of by-catch, increased variability in abundance and increased habitat modification. There are spectacular examples of ecosystem overfishing; for example, kelp forests, where overfishing of sea urchins has simplified them to the point where they lack trophic levels any higher than that of primary producers. [158] Eutrophication and plankton blooms in estuaries and nearshore areas have usually been explained by the addition of nutrients through land-based activities. However, overfishing of the animals that feed on microorganisms, like oysters, may be another cause. [77]

One of the key tasks of fisheries science is to agree how to predict the outcomes of specific management procedures on ecosystems. This goal will be facilitated by a practical definition of ecosystem overfishing [107] that translates concepts of "ecosystem health", "ecosystem integrity", "sustainability" and "biodiversity" into an operational structure that managers can use. If the attributes of ecosystems are to be conserved, they must be defined, measured and placed into an operational management system.

## Impacts of aquaculture and stocking on aquatic biodiversity

In many ways aquaculture is a response to declining wild harvest. When viewed simply as "filling the gap", as wild fisheries become less productive, aquaculture has been wildly successful. Global aquaculture (most of which is done in inland waters) provided 29% of global food fisheries production in 1996. The vast majority of cultured inland species are finfish, which are well behind crustaceans, molluscs and aquatic plants in marine culture. Most aquaculture production is in low-income, food deficit countries [50], although its role in providing affordable protein for the people actually living in those countries is not yet clear [172]. The problems and potential for aquaculture, especially in the developing world, are discussed in Svennevig. [157]

The stocking of water bodies with juvenile fish represents a massive injection of artificially produced juveniles into the environment for which there is no terrestrial equivalent. Stocking depends on hatchery production, a technology also employed in most aquaculture operations (although some still rely on the collection of naturally produced larvae). Data on global hatchery output are not systematically collected; however, a recent attempt by FAO to survey world hatchery output arrived at the astonishing figure of 180 million juveniles produced per day, 99% of which were finfish, and most of which were destined for release to the wild. [49] In North America alone, hatcheries release more than five billion juvenile salmon every year. [92]

This is alteration of biodiversity on a grand scale. The results of some enhancement programs, at least in terms of increased production and harvest, are known, but the subtler, long-term effects on biodiversity are not. In many enhancement programs, such as the large-scale release of hatchery-bred juveniles into Brazilian waters to "counteract" the effects of dams on migratory species, there is no effective assessment of results (H. Godinho, personal communication 2000; Agostinho and Gomes, this volume).

How does the culture of aquatic animals affect biodiversity? Like many other industries, aquaculture removes fish habitat, pollutes water, and adds chemicals. [12] At the *ecosystem* level, pathogens and parasites introduced through cultured aquatic species can disrupt natural communities. There are also more profound and less reversible, effects at the *genetic* level, and these depend on:

- Reproductive technologies and dependence on hatcheries;
- Source of broodstock;
- Containment (culture system);
- Concentration of interest and investment on only a few species.

## Reproductive technologies and dependence on hatcheries

Because most fish are very fecund, hatcheries have the capacity to produce large numbers of offspring from a limited number of parents. While mating schemes exist to lessen the impact of genetically uniform fish [85], it is easier for hatchery managers to derive most of their production from a limited number of breeders. As a result, hatchery-raised stocks are commonly much less variable genetically than wild stocks. [27] If these fish are released to the wild they compete with wild fish for space and resources and, if the stocking program is "successful", eventually affect the overall gene pool. [165] The history of enhancement of Pacific salmon in North America has been one of massive releases of hatchery fry; only recently have such programs begun to be re-evaluated and in many cases replaced by smaller, supplementation programs that depend on select wild stocks as parents.

Containment of cultured species and strains that can displace or affect the genetic makeup of wild populations is an issue that demands application of the Precautionary Principle. Unintentional release of hatchery-bred fish is common, and the risk is heightened by the even more rigorous selective pressure used to produce animals suitable for captive rearing. [68] The argument is often made that such fish are incapable of establishment in the wild by virtue of their selection for culture conditions or because they are an exotic species. The case of salmon farming in British Columbia clearly shows, however, that such assumptions are wrong. While few would argue that escaped Pacific salmon will breed with wild salmon of the same species, the industry's claim that escaped Atlantic salmon (an exotic species) cannot survive on the West coast of North America has been proven wrong. [59] The interbreeding of farmed and wild Pacific salmon may in fact be the greater overall risk to biodiversity, but the fact that escaped Atlantic salmon have managed to breed and produce surviving juveniles in British Columbia has stimulated furious debate. Introduced populations can also cause indirect changes in biodiversity through competition for mates or spawning sites; they need not reproduce to have a deleterious effect. [27] [69]

Several reproductive technologies, such as the ability to generate both sexes from the maternal line (gynogenesis) and new methods of multiplying the effects of germ cells, offer novel means of maintaining genetic variability in hatchery populations, primarily through increasing the effective population size. [140] Older methods, like gene banking, accomplish some of the same objectives. However, there is strong resistance from the conservation community to using such methods, because they are seen to encourage dependence on technological solutions and direct effort away from protection of habitat and responsible management.

The advent of transgenic fish introduces a new element of risk for biodiversity, raising fears similar to those for transgenic crops. Despite assurances from proponents that transgenic fish will be unable to compete with wild fish [41], the experience with Atlantic salmon in British Columbia has shown that even an "unfit" species can gain a toehold in a new environment. There is also concern that sterilization technologies, advanced as a way to ensure that released fish do not breed, are not foolproof. [53]

### Source of broodstock and seed

Hatchery programs are based on the genetic resources of broodstock that are either collected from the wild or traceable to wild animals. Because knowledge of the genetic structure of fish populations is still in its infancy, there is potential for stocking programs to produce large numbers of juveniles that do not reflect the genetic makeup of the populations in the area where they will be released.

When seed are collected from the wild, rather than produced in a hatchery, there is potential for local depletion of biodiversity. Two examples are intensive collection of milkfish fry in the Philippines, and collection of wild penaeid shrimp larvae or gravid females in Asia. [148] [14]

### Dependence on capture fisheries

There are two major trends in aquaculture. The first, a predominantly Asian trend, features non-intensive cultivation of herbivorous (plant eating) or detritus-eating species that are fed locally available feed. In this form, the overall trophic level (target species and its feed) is low.

In the second form of aquaculture, which aims at replacing the large carnivorous species whose supply from capture fisheries is unlikely to increase, feeds are derived mainly from capture fisheries. The overall trophic level is higher than the "Asian" form, and increasing. When trends in trophic level in aquaculture are analyzed it is clear that, if aquaculture in Asia is intensified, as is now happening in China, there will be a large increase in the global demand for feed products derived from capture fisheries. The overall trophic level of aquaculture will rise, a trend that is unsustainable. [119] Non-Asian aquaculture is already a net consumer of fish.

### Too much emphasis on non-native or non-local species

Small-scale freshwater aquaculture has the potential to provide food and modest income to poor families throughout the developing world. A recent survey of local Mexican fishing cooperatives showed that 98% of the fishing families wished to practice sustainable aquaculture, such as culture of an endemic oyster species. [73] In most areas there is a variety of local species that are well accepted. However, the culture systems promoted are frequently for exotic species, usually those for which standardized procedures have been developed. In Brazil, for example, culture of carps and tilapias, both exotic, is promoted over culture of the many local species that may in fact fetch a better market price. [180]

The implications of escapes of exotics, or even of domesticated versions of local fish, have already been discussed, but there are other subtle effects of aquaculture on biodiversity. In Vietnam, for example, wild and farmed strains of the indigenous mountain strain of common carp may be an important reservoir of genetic diversity with characteristics that are important for poor families; this particular strain, grown in rice fields, does not leave terraced fields when they are periodically flooded. An "improved" strain of carp, with better growth performance, is now being promoted for rice-field culture, yet this strain requires significant physical improvements in the pond environment. The biodiversity value of the original strain is now being recognized. [40] In Bangladesh, small native species of fish are important sources of food and income for rural people, and inhabit rivers, floodplains, ponds and paddy fields. Expanding crop production, increased use of agrochemicals and expansion of carp culture has reduced opportunities for capture of small native species. Possible solutions to this problem of biodiversity loss include encouraging conservation of wild stocks of small native species that can persist in water bodies used for aquaculture. [96]

## Impacts of invasive species on aquatic biodiversity

Although rapid air travel and economic globalization are relatively recent developments, the transfer of animal and plant species outside their normal ranges has been commonplace for over a century. Many such transfers have been deliberate (agricultural crops, for example). Others are accidental. All have the potential to compromise biodiversity, and aquatic biodiversity is especially vulnerable. Two-thirds of the freshwater species introduced in tropical countries have become established. [13] Introduced fish account for 97% of aquaculture production in South America. [54] Many introductions result in significant reconfiguration of ecosystem trophic structure. The effects of trout introduced into Australia and New Zealand, for example, have been far-reaching, including displacement of the native galaxiid species. [89]

Introductions of non-native aquatic species are summarized in FishBase's Introductions Table ([26]; www.fishbase.org). An idea of the magnitude of marine species dispersal may be gained from several examples.

- There are now 480 invasive marine species in the Mediterranean. Error! Reference source not found.
- Three thousand aquatic species (including plankton) are carried alive in ballast water every day. [19]
- A jellyfish introduced from the western Atlantic into the Black Sea disrupted food webs to the extent that the fish harvest collapsed. [19]
- The cost of eradicating the introduced freshwater zebra mussel in North America has been estimated as high as $400 million. [114] One species, the golden mussel *Limnoperna*, has become a serious pest in hydroelectric operations in Brazil (Fontes, personal communication 2000).

Exotic species may be introduced in many ways, including deliberate stocking, usually for recreational fishing but also for aquaculture (for example such widespread species as Manila clam and Japanese oyster, which are grown essentially uncontained); escapes of farmed species; escapes of transplanted ornamental species; and inadvertent transfers (for example in ballast water). Introduction of exotics is ubiquitous and has a long history. In India, for example, British colonists introduced English carp and tench for food and sport in 1870 and brown trout in 1899. Rainbow trout have been well established in the country since the early decades of the twentieth century and are one of the most serious impacts on aquatic biodiversity. [56] Tilapias, to take another example, are African species now grown in around

90 tropical and subtropical countries. Most of the species used have a 60-95% chance of becoming established in open water. [126] In the Venezuelan Orinoco, tilapia is known locally as the “pez universidad” (“university fish”), and Dehadrai [39] refers to their ecological effects in India as the “tricky tilapia trap.” Disruption of biodiversity would seem an inevitable effect of such introductions, although to date there have been few surveys aimed at actually documenting such effects. However, the notorious results of deliberately introducing the Nile perch to Lake Victoria, which resulted in the extinction of at least 300 species of native fish, shows that the potential for ecological damage is huge (Ogutu-Ohwayo [112] and this volume, [82]).

## Impacts of habitat alteration and pollution on aquatic biodiversity

If fishing is the single most important impact on aquatic biodiversity in the oceans, freshwater biodiversity is most affected by alterations to habitat, because inland water habitats are surrounded by land that has high economic value for agriculture, mineral extraction, timber harvest, housing and industry. Inland waters themselves also provide services, such as transportation, irrigation and hydroelectricity, that lead to changes in habitat. Pollution, while clearly a problem for both marine and freshwaters, is exacerbated in confined areas. Forestry is a major impact on watershed integrity because it removes ground cover, increases siltation, raises stream temperature and flow rates, and adds chemical pollutants (herbicides). Headwater streams are especially vulnerable. In countries like Papua New Guinea and Brazil, where timber extraction is a major economic activity, forestry is a major threat to flowing water habitats. Effects of forestry practices on temperate aquatic habitats are detailed in Harvey *et al.* [64]

Inland waters are impounded (for flood control and electricity), extracted for agriculture, industry and drinking, and drained to eliminate wetlands. The pressures on inland waters are usually multiple. It is not uncommon, for example, to see a major waterway that has been repeatedly dammed, that receives pollution from nearby industry and riparian (riverside) agriculture, that provides water for local irrigation and drinking, and that supports community and sport fisheries. Such a scenario, it should be pointed out, is not unique to developing countries; it could be found as easily in Japan as in Brazil. And those impacts are only local. On a grander geographic scale, where impacts are felt from beyond the immediate watershed, inland waters are severely affected by pollution (for example, acid rain) and schemes for linking separate basins.

### Acid rain

Acid precipitation is a consequence of industrialization and can occur hundreds of kilometres from the source of the pollution. The scale of acidification is global and the effects on freshwater fauna can be catastrophic. In Sweden alone, more than 6,000 lakes have been limed to preserve fish populations. [51] Depending on where the precipitation occurs, acidification of fresh waters can affect biodiversity on the species and subspecies level. The largest fish gene banking program in the world, for example, was begun in Norway in the mid-1980s to conserve population-level genetic diversity in Atlantic salmon whose numbers had been affected by a combination of acidification and infestation by a parasite introduced from fish farms. [164] Fortunately, both problems were reversible, but not before a massive effort had to be made to ensure that population-level genetic diversity was not irrevocably lost. In most parts of the world, of course, investment in gene banks to protect aquatic biodiversity is impractical and too expensive. In the Norwegian case, salmon were the species for which heroic attempts to conserve biodiversity were made; however, acidification of inland waters has far-reaching and complex effects on other members of the ecosystem, which can affect more “economically important” species indirectly. [89]

### Water diversion projects

Schemes for connecting river basins, or altering riverbeds to improve navigation, can affect aquatic biodiversity in several ways. Dredging increases siltation. Filling in of areas for agriculture or development removes breeding areas for many migratory species. [180] The Amazon, the world’s largest rainforest and river ecosystem, is under pressure from fishermen, ranchers, gold miners, foresters and others who are extracting the resources of the region. [58] [7] Alterations of river courses can also lead to mixing of endemic flora and fauna that have evolved in isolation. The proposed scheme for transposition of the Sao Francisco River in Brazil, for example, which is the latest version of an idea that first arose in 1847, will provide irrigation water for the arid Northeast. [25] The project will have irreversible impacts on biodiversity by connecting river systems in which aquatic fauna have evolved independently. The proposed Hidrovia water development project, intended to provide improved transportation into the Parana-Parguay watersheds, implied such massive changes to aquatic life that the project has been put on hold as a result of concerted protest (see www.irn.org).

### Dams

Dams are an obvious impact on life in rivers. The building of large dams has increased by a factor of seven since the 1950s, and dams now impound 14% of the world’s runoff water. [162] While the pace of dam construction has slackened in some industrialized countries, the demand for electrical power and flood control in developing countries means that there are many more dams on the drawing board. [55] And not all industrialized countries are slowing down – Japan is now preparing to dam its last wild river, and the demands of industrialization and population growth in China are behind the largest dam project ever, the Three Gorges Dam on the Changjiang (Yangtze) River. Among the many environmental effects of that dam will be the obliteration of floodplain and oxbow habitat vital for reproduction of a large variety of migratory and non-migratory species (Li Sifa, personal communication 2000).

Dams severely disrupt water flow, preventing sediment from being carried downstream and drastically increasing the transit time of water from its entry into the river until it reaches the sea. [131] Flow regulation by dams prevents movement of animals, changes seasonal regimes, changes downstream temperatures and nutrients and alters channel structure. [17] Removing the natural flooding regime has profound effects on biodiversity, because the floods stimulate aquatic and riparian productivity, catalyzing the exchange between sediment biota and organisms in the water. [111] [3]

Dams are especially devastating on migratory fish species. In North America, effects of dams have been well studied. On the Colorado River, for example, all native fishes in the lower reaches are in decline or extirpated. [106] Dams in the Columbia River basin now block off more than a third of the original salmon habitat. [92] In North America, the response to the effects of dams on migratory patterns has been to install fish ladders and massive hatchery programs, which have worked to the extent that selected populations of a few economically important species, such as salmonids, have been maintained. But, as we have seen, hatchery programs do not replace biodiversity; they dilute it, so that while absolute numbers of some species may be maintained, the population genetics of the species have been profoundly altered, with consequences for the ultimate survival of the species. [138]

Ladders and hatchery programs have been enthusiastically exported to developing countries for application to tropical migratory fish species. The results have been disappointing, or simply not measured. Many of the migratory tropical species, which travel distances every bit as long as their temperate counterparts, cannot negotiate conventional ladders, so expensive retro-fits of North American and European technology have failed. Hatchery programs, while sometimes officially mandated as a legal mitigation alternative to ladders, suffer from lack of husbandry technology for native species, poor supply of broodstock, lack of knowledge of life histories and habits, and above all an almost complete ignorance of their ultimate effect. [3]

The organization of the World Commission on Dams, a review commission set up to investigate the effects of dams on communities and ecosystems, reflects the severity of dam effects. [168] The WCD, disbanded in 2001, was especially active in examining the effects of dams on human settlements, but their impacts on fish were also considered. Its work has in part been taken over by a Dams and Development Unit, currently hosted by UNEP but based in South Africa.

## Impact of climate change on aquatic biodiversity

Most scientists now agree that ecosystems around the world will be profoundly influenced by climate change. Global warming has important consequences for aquatic communities and will affect fisheries in ways that are just now beginning to be discussed. [9] [10] [86] By the year 2100, climate change is expected to be the major threat to biodiversity in inland waters, replacing the effects of land use and invasive species. [139] Those freshwater animals that cannot tolerate changes in temperature or water availability will be the first to be affected.

Most current models predict a global mean surface temperature increase of 3-5$^{o}$C, although prediction of regional effects is more difficult. [65] Whatever the finer-scale effects in different regions, it is clear that temperature increases in this range will have many effects on aquatic systems, including increased water temperature, changes in stream flow, changes in lake size and thermal layering, a rise in sea levels and consequent loss of estuarine habitat, and a great increase in “extreme events” like floods and droughts. [93] [123] Any of these consequences alone will change the distribution and abundance of aquatic life; in combination their effects on fisheries may be drastic. Some examples:

- The ranges of many species will shift north. Warm-water species will become invasive. [142]

- A two-degree increase in temperature will reduce freshwater salmon habitat by 35%. [83]

- Shallow lakes and wetlands will dry up, and the margins of deeper ones will decrease. [102]

- Species that depend on transient floodplains for reproduction and rearing, such as tropical migratory species, may experience a severe reduction of habitat.

- For economically important species that are already sensitive to natural decadal shifts in climate, global warming will affect ocean productivity and marine survival.[11] The result will be larger fluctuations in abundance of adults available for harvest.

Climate change, although man-induced, is the most difficult of the many impacts on aquatic biodiversity to undo. Its effects are global, not regional or local, and they occur at every level in the aquatic ecosystem. Habitat can be recovered, and fishing and pollution can be reduced, but climate change dwarfs all of these in terms of scope and intractability. The fisheries management challenge of the next decades will be to scramble for models that produce scenarios of fisheries effects, to test these predictions, and to develop management systems that clearly recognize the impact of climate change. For no other threat is the need for sectoral cooperation between regulators, legislators, policy makers and scientists so urgent.

## Suggested development investments

### Biodiversity implications of aquaculture and enhancement

In many developing countries, small-scale culture of finfish is promoted. Frequently, the species promoted are exotics (e.g. tilapias), "improved" strains of local species or transplants from other river basins within a country. The genetic effects of escape and establishment of these fish are usually ignored. In the case of enhancement or stocking, releases to the wild are deliberate, but the animals released are genetically dissimilar to wild types. In most such "enhancement" programs, there is no assessment of results. For Asia in particular, the trend in aquaculture is toward intensification, so that operations move from being low-trophic-level producers of protein to high-trophic-level fish that are actually net protein consumers. Extensive culture makes better use of natural ecosystems, for example paddies and floodplains, and should be promoted as a way of sustainably using existing aquatic biodiversity.

Small-scale aquaculture projects should thus acknowledge or attempt to quantify the value of native biodiversity. Where enhancement is promoted as a means of increasing livelihoods, local communities should be enlisted in monitoring its effects, both in terms of increased protein and changes to genetic makeup of wild stocks.

### Stocking reduces biodiversity

The consequences of large-scale releases of hatchery-bred fish into the wild are rarely if ever considered or discussed with communities, and state extension departments are either unaware of them or unwilling to raise them. An investment in building user and extension awareness of the genetic effects of aquaculture and stocking would send a powerful message about the value of biodiversity and stimulate research on technologies for developing aquaculture systems that make use of it. A strategy that encourages networking between state agricultural departments, commercial large-scale fish farmers, state biodiversity planners, university researchers and communities is recommended. This strategy lends itself well to regional workshops.

## Key bibliographic resources

Bonfil *et al.* 1998. **Distant Water Fleets: an Ecological, Economic and Social Assessment**. [17]

Substantial report, prepared for the World Wildlife Fund and also available on the WWF website (www.wwf.org).

**FishBase**. www.fishbase.org.

The authoritative interactive metadatabase on fish. A repository of information on taxonomy, biology, ecology, occurrence and utilization.

Hanna, S. S. 1999. **From single-species to biodiversity - making the transition in fisheries management**. [62]

Insightful paper that captures the present dilemma of fisheries management.

**IUCN Invasive Species Specialist Group**. http://www.issg.org

The Invasive Species Specialist Group (ISSG) is part of the Species Survival Commission (SSC) of the World Conservation Union (IUCN). ISSG provides advice on threats from invasives and control or eradication methods to IUCN members, conservation practitioners, and policy-makers. The group's activities focus primarily on invasive species that cause biodiversity loss, with particular attention to those that threaten oceanic islands.

Jackson *et al.* 2001. **Historical overfishing and the recent collapse of coastal ecosystems**. [77]

A provocative new analysis of the effects of overfishing using paleoecological, archaeological and historical data in addition to fisheries records and ecological data. The authors conclude that, for coastal marine areas, “pollution, eutrophication, physical destruction of habitats, outbreaks of disease, invasion of introduced species and human-induced climate change all came much later than overfishing in the standard sequence of historical events.”

Kaufman, L. 1992. **Catastrophic change in species-rich freshwater ecosystems: the lessons of Lake Victoria**. [82]

Summary of the well-known case of the effects of introduction of an exotic species into a complex ecosystem; read along with Oguto-Ohwayo, this volume.

Murawski, S. A. 2000. **Definitions of overfishing from an ecosystem perspective**. [107]

Contains useful technical definitions of over-fishing, and its consequences.

Pauly, D., and V. Christensen. 1995. **Primary production required to sustain global fisheries**. [116]

Fundamental and often-cited paper that explains the "cost" to the ecosystem, from the bottom up, of providing fish for harvest.

Perez, J. F., and J. J. Mendoza. 1998. **Marine fisheries, genetic effects and biodiversity**. [121]

Readable and informative review of the effects of marine fishing on the genetic makeup of fish populations.

Schindler, D. W. 2001. **The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium**. [142]

An attempt to summarize what will happen to freshwater ecosystems and fisheries as a result of global warming, with Canadian freshwaters as an example.

Stephenson, R. L. 1999. **Stock complexity in fisheries management: a perspective of emerging issues related to population sub-units**. [155]

Introduces the concept that there is significant biodiversity within species that must be conserved in management.

Svennevig, N., H. Reinertsen, and M. New (Eds.). 1999. **Sustainable aquaculture: food for the future?** [157]

Sourcebook for recent debate on effects of a broad range of aquaculture operations on biodiversity.

Waples, R. S. 1995. **Genetic effects of stock transfers of fish**. [165]

Important review of effects of transplants of stocks, enhancement and hatcheries.

World Fisheries Trust. 2000. **Annotated bibliography on the effects of dams on fish and fisheries**. [177]

Comprehensive database drawn from published and unpublished material, with approximately 10,000 citations.

WRI/UNEP/UNDP/World Bank. 1998. **World resources 1998-99**. [178]

A comprehensive summary of the state of world resources, with sections on marine and freshwater biodiversity.

# Part Four - Key Biological and Social Concepts

As we enter the first decade of the new millennium, fisheries management is everywhere in ferment. For biodiversity planners, who must promote the sustainable use of biodiversity at the inter-ministerial and inter-government level, it is essential to understand two concepts that infuse the current debate. The first is biological, and concerns relationships between organisms in nature. The *ecosystem approach* colours current discussion and decision making, and is exemplified here by the concept of large marine ecosystems and the use of protected areas as management (not simply "conservation") tools. The second key issue– *governance*– is a social one: it concerns relationships between people.

## Key biological concept: the ecosystem approach

*WASHINGTON, DC, June 15, 2001 - A coalition of 105 conservation and fishing organizations called Thursday for a major shift in the direction of marine fisheries management. The Marine Fish Conservation Network (MFCN) urged Congress to adopt a strategy of multi-species "ecosystem based management" of U.S. fisheries instead of using only a "single species" approach. The change would require fishery management councils to address the ecological interdependence and interactions of marine species before setting catch levels* –Environmental News Service.

Fisheries management, it is commonly said, must adopt an ecosystem view if fisheries are to be sustained. It is difficult to argue with this statement. What *is* difficult is to imagine how single-species management systems could persist for so long in a professional culture where even the most basic biological education is based on such fundamental concepts as food webs and the interdependence of living things. The answer, of course, is that traditional management models worked well enough for many years, and it took a determined effort on the part of fishing nations to demonstrate that the resources of ocean and river were not limitless. When one stock or species was fished to unprofitability, there were always others to take its place.

Evidence for the failure of fisheries management is now abundant. Fisheries crashes are much-publicized and repeatedly cited as evidence that a new approach is needed, but they are not in fact the most compelling evidence (as we have already noted, many crashes are natural events). [67] In fact the more insidious, and least refutable evidence of the damage done by bad management comes from studies where an attempt has been made to look not only for declining catches but also specifically for ecosystem effects. The most compelling of these studies are the ones that have spawned the ominous term "trophic mining."

### Fishing down the food chain

Fisheries extract animals, and reflect the animals' value to people as food. Although the fisheries literature is now full of studies of the ecosystem consequences of harvest (recently reviewed, for example, in [71]), the roles played by the target species in maintaining ecosystems still tend to be ignored in traditional management. However, it is those ecosystems that sustain and fulfill human life (this is the concept of "ecosystem services"; [37]).

Leaving ecosystem effects out of the management equation is shortsighted, as can be seen from the common practice of "fishing down the food chain."

Trophic mining, or fishing down the food chain, describes the cascading effect of harvesting one species beyond its capacity to replenish itself. [117] [120] When global fisheries landing statistics are analyzed in terms of trophic level – the place of an animal in the food chain – there is a clear trend toward catching fewer large, fish-eating species and more small, plankton-eaters. The decline is not dramatic the way a fisheries crash is dramatic, but it is steady over the past forty-five years. Although marine systems are better studied, the same decline in trophic level can be seen in inland fisheries too. The logic of "replacing" the declining large, carnivorous species by farming them does not stand up to trophic level analysis; as we have seen, an increase of trophic level in farmed fish simply elevates the demand for lower-trophic level species to feed them. [120]

Fishing down the food chain speaks of profound effects of fisheries on ecosystems. We have already seen that global fisheries harvest continues to grow (if slowly), which means that we are catching more, but smaller, fish. The debate now is about which attributes of ecosystems are best for developing management systems. Trophic level is a useful index in ecosystem-based management [120], although it is clear that, as an index that relies on historical data sets, mean trophic level may in fact best be viewed as a key diagnostic tool that can tell managers about the sustainability of a fishery. Monitoring declining trophic levels, however, is no more likely to make fisheries sustainable than monitoring blood pressure will stave off a coronary. To halt the slide in capture fisheries, management must change.

### Keystone species

Not all fisheries failures result from the lack of an ecosystem perspective. Systematic overfishing and destructive harvesting practices, for example, are things for which there already exist remedies. The ecosystem concept is more valuable as a frame of reference that will eventually produce new management systems but will in the meantime change the way the existing systems are used. An example is increased awareness of the concept of "keystone species." The keystone concept is useful because it places species in the context of an ecosystem, and calls attention to the cascade of effects that occur when the ecosystem becomes modified, usually by harvest. Keystone species are those agreed to play a central ecosystem role, and while there is a danger that keystone species are equated with "charismatic" ones, the concept has value in that it promotes a holistic view. [151]

A good example of an aquatic keystone species is Pacific salmon, a multi-species, multi-population assemblage presently at the centre of vigorous debate over management. Two recent reviews discuss the decline of many Pacific salmon populations and the ecosystem role of salmon. [64] [30] Salmon are a good example of fish that serve as passive links between aquatic, aerial and terrestrial ecosystems, particularly through the action of scavengers. In the case of coho salmon, spawned-out carcasses are a food source for 22 species of mammals and birds [29], as well as for stream invertebrates. Salmon carcasses also transmit nutrients into the forest, feeding riparian vegetation. Considered in this ecosystem light, the consequences of declining salmon are evident not just for people, but for a large and tangible web of interdependent organisms. Identifying salmon as a keystone species benefits the entire ecosystem by refusing to consider the species in isolation, as simply the only thing to be "managed".

The socio-economic consequences of fish disappearing from the diets of avian and terrestrial animals are clearly appreciated when they are seen as keystone species. In Glacier National Park, for example, the population of landlocked kokanee salmon collapsed when shrimp were introduced to increase fish production, and had the opposite effect of out-competing juvenile salmon for available zooplankton feed. [154] The following sequence of events occurred:

- Angler harvest declined to zero;
- Bald eagle populations declined 96%;
- Visiting bird-watchers declined 98%;
- Populations of coyote, mink, deer and grizzly bears declined.

Within eight years of introducing the shrimp to the lake ecosystem, recreational activities in the park had dropped drastically, as a direct result of loss of ecosystem services provided by a keystone species. This dramatic example, which could be repeated for many other species, serves simply to illustrate the dimensions of the change in thinking that will be needed if management is to become truly ecosystem-based. As a keystone species with a central role in productivity and biodiversity of several ecosystems, anadromous salmon bring together management issues not only for the ocean and river, but also for forests, floodplains and estuaries. Separating management of one system from all the others is risky; for example, forest practices have long been accepted to affect salmon, but as a keystone species the role of salmon in *building* forests must also be considered. The salmon example is one more case where the impacts on aquatic biodiversity are multiple and involve sectors of society apart from fisheries management. The challenge to society of finding new ways to integrate management of all these sectors, so that aquatic biodiversity is conserved, is the challenge of governance.

## Large Marine Ecosystems

A relatively new example of ecosystem thinking is the Large Marine Ecosystem. LMEs were first proposed as a management concept in the mid-1980s. [144] LMEs are coastal areas that extend from river mouths to the outer boundaries of continental shelves and the outer margins of coastal currents. They are geographically extensive (200,000 km$^2$ or more) and politically complex. The fifty LMEs include the marine areas most heavily fished and most subject to stress of resource extraction, habitat loss and pollution. [145] Laevastu [88] reviews their utilization by man.

Management of large marine ecosystems reflects principles adopted by the United Nations Convention for the Law of the Sea (UNCLOS), Agenda 21 and the Global Plan of Action (GPA) for the Protection of the Marine Environment from Land Based Activities. They are an ecological framework for achieving the objectives of UNCED and the Convention on

Biological Diversity. [143] Hence the Global Environment Facility, the chief funding mechanism for the Convention on Biological Diversity, has encouraged proposals for ecologically focused assessment and management activities in LMEs. Such projects generally involve a number of participating nations (thirteen, in the case of the Caribbean Sea LME).

Perhaps as a reflection of its large geopolitical scale, the LME concept remains difficult to define. Critics note the lack of knowledge of ecosystem functioning, the historic failure to predict even simple, single-species events, the lack of technical tools to study LMEs and evaluate different management options, and even the lack of explicit management goals. [115] The ambitious LME projects funded or proposed to the GEF will yield invaluable experience on managing fisheries for biodiversity, and will help to provide answers for these criticisms.

### Protected areas or reserves

The only way to completely preserve ecosystems from the effects of fishing, of course, is to stop fishing. Criticisms that we lack the knowledge and tools for managing ecosystems becomes irrelevant if protected areas are the management tool, and the research needed to implement protected areas is identical to the research needed to manage large marine ecosystems. [115]

Protected areas address a critical hurdle that must be overcome if we are to achieve true “ecosystem-based management.” While it is repeatedly said that single-species models must be abandoned in favour of multi-species, or even full-ecosystem, models, the data necessary for constructing and operating such complex models do not yet exist. Some critics argue that fisheries science is in fact *incapable* of constructing and applying ecosystem models, and that aquatic ecosystems are, in effect, unmanageable because of the very high level of uncertainty their complexity implies. An alternate, or complementary, strategy, that does not involve vastly accelerated data collection, is to “hedge bets,” to reduce risk by diversification, rather as an investment portfolio is made more robust by buying stocks from companies with different risk levels. Prohibiting harvest in protected areas is “bet hedging.” It is the simplest way to diversify fisheries management [90], and a classic application of the precautionary principle.

While there are more than 8,000 terrestrial protected areas, marine protected areas are more recent (established within the last few decades), and much fewer in number (around 1,300). There is, for example, 1500 times as much terrestrial area designated as “no-take wilderness” in the United States as there is aquatic. [19] Fully one quarter of all marine protected areas are in Australia . [16] The social mechanisms involved in establishing and maintaining protected areas tend to come from outside the fisheries management culture, perhaps reflecting the long history of terrestrial conservation using protected areas. In this sense, protected areas serve the very important social function of bringing together conservation biologists and fisheries biologists, two spheres that have until recently orbited in different galaxies.

Protected areas can range from no-take reserves to multiple-use areas that encourage fishing and recreation. In the United States, the 12 national marine sanctuaries cover less than one per cent of US waters, and less than 0.1% of the actual “sanctuaries” is off limits to fishing. [1]

The degree of protection varies and is by no means always absolute. In California, for example, commercial and recreational fishing are allowed in all national marine sanctuaries. [108]

Establishment of reserves requires some knowledge of fish community dynamics in the area in question. For example, some areas are sources of larvae and juveniles, and some are "sinks," areas that do not contribute significantly to future generations. The amount of knowledge needed before establishing a protected area is a matter of debate: if there is too little, the ability to link protected areas into a productive network is lost; if too much time is spent gathering information (sources and sinks, for example, are identified for only a few species), the opportunity to establish any areas at all may be lost. [134]

## Functions of protected areas

Marine reserves protect ecosystems and they conserve biodiversity. Fisheries scientists now accept that protected areas can accomplish many of the goals that conventional management has failed to achieve, and that exploited populations *do* recover in protected areas. Prohibiting exploitation means that a more natural age structure and genetic base are preserved, because there is no harvest that selectively removes individuals based on age or size. In reserves, breeding opportunities are not modified by harvest, so the effects of fishing on biodiversity are eliminated. [79] A management system based on protected areas may actually maximize catch while protecting stocks, by permitting greater fishing intensity over a smaller area. [90]

One major benefit of protected areas is that they offer future generations an opportunity to appreciate the richness of aquatic life. Fishermen, and the public, may assume that the variety of species now present is the variety that has always been there. In the absence of pristine areas, such an assumption is only reasonable. Simply by existing, reserves provide dramatic evidence of how much humans have altered and simplified aquatic ecosystems; they are a constant reminder and reference point and hence a powerful stimulus to conservation. They are also available for scientific study, a prerequisite if we are ever to understand aquatic ecosystems well enough to "manage" them. Most aquatic biologists, it must be remembered, have never worked in an undisturbed system. Finally, protected areas can play an important role in public awareness about aquatic ecosystems, a role that can be disproportionate to the actual size of the protected area. A good example is Race Rocks, a marine protected area in British Columbia that, while small, generates a wealth of information that is skillfully disseminated by electronic means (www.racerocks.com).

Protected areas are reproductive refuges, and as such their size needs to be carefully considered so that they are successful in "seeding" outlying areas. They also impose requirements for management, monitoring, policing and public awareness that demand new kinds of governance. There appears to be no direct correlation between a country's economic status and its ability to effectively manage an MPA; in fact, marine biodiversity may actually be easier to protect in developing countries where more people have a direct stake in earning their livelihood from the sea ([159], see also Alcala this volume for a discussion of protected area experience in the Philippines and the success of community-based management).

### Freshwater protected areas

The ecosystem service value of freshwater habitats, when expressed per unit of area, far outstrips that of any other habitat type, including open ocean and coastal marine [36], yet protecting freshwater areas is problematic. Formal protection for freshwater areas is less common than for marine, and protected freshwater areas are less likely to be used as fisheries management tools. Frequently they will be part of the park system. The Ramsar Convention provides for designation of significant wetlands as Ramsar sites, although the designation carries no automatic prohibitions on harvest and no explicit link to fisheries as is common with marine protected areas. Functioning ecosystems are obviously important for freshwater habitats, but this raises an important problem for conservation, namely the vague boundaries of freshwater habitats. Rivers, lakes and wetlands don't exist in isolation; instead, they are part of drainages or watersheds, and they change with the seasons. Protecting a part of a watershed, for example by listing a wetland as a Ramsar site, is better than nothing, but that protected site will always be vulnerable to change in the overall catchment, which may cross international boundaries. [104] Once again, the unique nature of freshwaters affects their conservation.

Protecting freshwater biodiversity needs to reflect the fact that it is the medium itself, not simply the organisms in it, which determines the makeup and functioning of ecosystems. Freshwater ecosystems are constantly changing, so concentrating efforts on preserving a single species, as works well for terrestrial conservation, is not necessarily the best strategy. And because, overall, most inland fisheries are small-scale and spread out along watercourses, justifying the protection of a large freshwater area in order to "seed" adjacent areas for fishing is a weaker argument than for marine areas. Enforcement and monitoring are also more difficult, because the pressures on freshwater habitats come not mainly from fishing but from other human activities. In most cases, designating a freshwater habitat as a no-take zone is not going to save it.

## Key social concept: governance

'Governance' is a relatively new term first introduced in the social sciences. It refers to the systems that society erects to arrive at rules and to apply them. Systems of governance reflect cultural norms and political stamps; they can range from consensual and participatory to authoritarian. Governance focuses on the interaction between the state, the marketplace, and civil society, and can be defined as the arrangements by which people and government interact to solve societal problems. [87] Governance is about relationships, while 'government' refers to actions. The study of governance reflects the need for new kinds of cooperation based on growing interdependencies in society.

Systems of governance are presently characterized by an increase in the number of parties involved in decision-making and managing. The sustainable use of biodiversity is an excellent example of a field where this trend is very apparent, since it requires collective action at many levels. An intriguing parallel could be drawn between the trend toward considering whole ecosystems in management of biological resources and the trend toward inclusiveness in governance. On the global scale, the 181 Parties to the CBD are evidence of such involvement in global governance, while more locally the trend toward participatory research and management is marked.

Governance becomes complex when a resource is affected by many kinds of activities by many sectors of society. Aquatic biodiversity, especially as man affects it, is a good example. Pacific salmon illustrate this complexity, with symbolic, spiritual, recreational and economic importance for millions of people over a time span of millennia. Salmon were the basis for the earliest cultures in western North America, yet they must now contend with demands on their habitat that include dams, irrigation, mining, logging and cattle grazing – not to mention fishing. Managing a resource with so many stressors demands systems of governance that recognize this complexity.

### Fisheries co-management as an example of changes in governance

In fisheries as in other areas of resource management, the appeal of top-down, state-initiated and controlled management is fading, and new initiatives are coming more and more from civil society – from environmental and social organizations, communities and indigenous people. Traditional "command and control" management models have not worked to conserve biodiversity, partly because they ignore the underlying economic forces that act at the local level. [80] Participatory management ("co-management") is becoming more common in fisheries, and reflects the realization that the biological and social issues are too complex and interconnected for any single organization to handle. That is not to say that all management must now be "bottom-up," just that there needs to be a fairer representation of knowledge and interests. Excellent initiatives can come in either direction.

Traditional fisheries management tries to anticipate the effects of particular management measures on the abundance of fish. In a new governance system, the science used to manage fisheries will need to anticipate and measure effects not only on fish, but also on the societies that harvest them. Hence, data collection will be broader, and will employ the tools of social science. [133] The old approach, where the biology was done first and the social and economic studies followed, will gradually be replaced by simultaneous data collection and integration that spans several disciplines. At present, the changeover is just beginning, with both camps warily trying the idea on for size.

In fisheries management, especially where biodiversity is a consideration, the process of beginning to share responsibility will be particularly difficult, because the State, having thrown all the up-to-date tools of science at the problem, can hardly be said to have achieved sustainable harvesting. Fisheries managers are used to being reminded of this. As with all models of social interaction, there is much tinkering to do on the new fisheries management models, and many problems have surfaced. User groups, if they are to collaborate, need new skills for group negotiation and dispute resolution. In cases where many user groups contend for a genetically complex group of species and stocks, for example, the training and technology for enumeration and monitoring have traditionally resided in government. When local communities become involved in decision making about, say, allocation and harvest methods, they need to confront hard questions about technical infrastructure and data sharing that cross the traditional lines of competence. For example, do twenty years' data on spawner aggregation suddenly become the "property" of a community group struggling to understand more about its share in the harvest of those fish? Should they receive training in interpreting such extensive databases? Do they even want to? And who pays? These are real-life questions, and they are typical of any situation where responsibility is devolved.

Another example of the realities of co-management comes from Barbados, where partnership between government and fishing cooperatives is actively encouraged in the development of management plans. A recent study of the process pointed out several pitfalls, including the obvious need of fishermen to give fishing a higher priority than meetings and a tendency to seek solutions from government rather than through collective action. [98] Where local control of fisheries is sought and attempted, the existence of a strong local personality has helped (MacKay, this volume), which promotes the not-too-surprising observation that there is a delicate balance between participation and leadership.

## Agreements between national governments

The changes in fisheries governance are happening at many levels. National-level management is important simply because most of the world's marine production, and all of its freshwater production, is within national jurisdictions. And indeed, national agencies are cooperating more with local communities. However, there are also a number of important agreements *between* national governments that, taken together, are strong evidence of a shift in thinking about aquatic resource management. States are capable of signing fishing agreements that include all parties in a significant fishery. A good example is the *Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea*, signed by Japan, Korea, China, Poland, Russia and the United States. The Pollock agreement is one of the few enforceable fishing agreements signed by all the interested parties. [17]

Environmental politics have figured prominently in the change in fisheries management, and certainly influenced the major multi-national agreement affecting fisheries governance, namely the Convention on Biological Diversity. The CBD obliges states to produce action plans for conserving biodiversity (Article 6), and led to the adoption of the Jakarta Mandate on Marine and Coastal Biological Diversity in 1995. This agreement made marine and coastal areas the first major ecosystems to be systematically addressed by the Convention, a move that instantly raised the international profile of aquatic biodiversity. The CBD affects fisheries management through enhancing multi-species and ecosystem-oriented research; through promoting *in situ* conservation in protected areas (Article 8); and through helping countries focus biodiversity priorities as a result of participation in the Conference of the Parties. [70]

Other major international agreements that support the trend to new systems of fisheries governance include:

- The United Nations General Assembly Resolution on large-scale pelagic drift net fishing http://www.un.org/Depts/los/general_assembly/documents/ares55_8e.pdf

- The United Nations Convention for the Law of the Sea (UNCLOS) http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm

- UNEP's Global Plan of Action for the Protection of the Environment from Land-Based Activities (GPA) http://www.gpa.unep.org/

- 1997 guidelinesl on ballast-water management to prevent the spread of alien species by the International Maritime Organization of the United Nations (IMO) http://globallast.imo.org

- The UN Agreement on Straddling Stocks and Highly Migratory Species http://www.un.org/Depts/los/convention_agreements/texts/fish_stocks_agreement/CONF164_37.htm;

- The Kyoto Declaration adopted at the Conference on the Sustainable Contribution of Fisheries to Food Security http://www.fao.org/fi/agreem/kyoto/kyoe.asp, and

- The FAO Code of Conduct for Responsible Fisheries. [44]

Some of the above agreements have significant implications for sustainable use of aquatic biodiversity. Their relevance to fisheries management and their effectiveness and enforcement have been reviewed (for example [66 167 70]). The Agreement on Straddling and Highly Migratory Fish Stocks [161] deals specifically with the application of the precautionary approach, which necessitates a different way of dealing with the large uncertainties inherent in fisheries management science. [133]

## The FAO Code of Conduct for Responsible Fisheries

The FAO Code of Conduct for Responsible Fisheries, with accompanying Technical Guidelines [44] is an authoritative digest of the principles of sustainable fisheries. It is as valid for nations as it is for local communities involved in fisheries regulation. Article Seven (Fisheries Management) deals with many of the important biodiversity-related issues discussed in the present report, including:

- excess fishing capacity,

- the special requirements of developing countries and small-scale, subsistence and artisanal fisheries,

- the conservation of habitats and ecosystems,

- effects of humans on habitat,

- aquaculture,

- by-catch and selective harvest,

- the need to base management on the biological and genetic characteristics of stocks,

- the need for gathering knowledge on social and economic impacts of fisheries management and conservation,
- coastal zone management, and
- the need to adopt a precautionary approach.

As a blueprint for sustainable use of aquatic biodiversity, at least so far as fisheries affect it, the Code is authoritative and unassailable. It can and should be used for developing policies, and is, for example, the basis for certification by the Marine Stewardship Council (MSC), an organization set up in the mid-1990s to promote sustainable fishing by harnessing market forces. But fisheries certification is expensive, and the Code is voluntary. Sadly, it is safe to say that most on-the-ground fisheries managers have never heard of it. Biodiversity planning for fisheries already has a first-class conceptual tool in the Code; it is up to planners, policy makers and managers to use it.

## Governance and the cost of conservation

Estimates of the annual value of the goods and services provided by biodiversity range from $2.9 to $33 trillion. [36] Estimates of the cost of *preserving* that biodiversity vary with the method proposed, with protected areas a particularly efficient option. Whatever the final bill, finding the money to pay for biodiversity depends on mechanisms through which society can justify redirection of funds. The CBD provides such a mechanism, with parties being required to identify and regulate activities that adversely affect the sustainable use of biodiversity (Article 7). The convention also enjoins parties to provide money to developing countries for biodiversity conservation, through the Global Environment Facility (GEF). The GEF has already invested heavily in protected areas.

One of the easiest adverse impacts on biodiversity to identify may be government subsidization of resource use. “Environmentally perverse subsidies” are estimated at US $950 billion, of which $20 billion goes to subsidize commercial fisheries. Such subsidies produce massively over-capitalized fleets, keep resource prices below market level and encourage over-exploitation. Worldwide, fisheries costs exceed revenues by as much as US $50 billion. [32] Vessel subsidies mean artificially low costs for operators and investors and, together with subsidies for research and management, have led to over-use of the resource. [62] Even fractional reduction of these subsidies, as mandated by Article 7 of the CBD, would pay for a comprehensive global biodiversity conservation program. [78] [Comment: the EU has tried hard to do this – I think I sent you some info – if not I could find it and insert here] Whether nations are prepared to re-allocate expenditures in this way depends on the extent of dialogue between interests competing for the resources. As we have seen, for fisheries, those interests are extremely diverse.

## A shift in governance at the agency level

Perhaps the single greatest change needed in governance is to shift from managing single species to managing groups of species or ecosystems. The FAO Code of Conduct spells out what needs to be done, but putting its principles into practice is an enormous challenge to policy makers, regulators, and all the people who live off fisheries. Despite the need for national and international policies, it is probably at the implementation level – the level of individual fisheries agencies and their partners – where the real challenge for institutionalizing biodiversity lies. [62] It is at this operational level that governance needs to change, and it is this "front line" of fisheries management that readers of this report should constantly envisage.

An idea of the challenge facing these agencies can be gained from considering how "managing for biodiversity" differs from traditional management: [62]

- Regulations will be based on ecological, not political, boundaries;
- More species (i.e. not just the target species) must be protected, and scientific information is needed on those species;
- Species interactions need to be accommodated;
- More enforcement needs to occur at sea (e.g. protected areas and gear use).

Making these changes will require fundamental changes in the design of the institutions that manage fisheries, particularly at the agency level. The cost will be high, although not in relation to the amount already spent on perverse subsidies. However, there is growing experience that we can learn from. Co-management or cooperative fisheries management has begun to accumulate a track record, and, as is clear from the case studies in this report, some lessons have been learned. In Canada, for example, the political and social complications imposed by the sharing of fisheries responsibilities between aboriginal and non-native people have led to many experiences in co-management that provide valuable lessons for other jurisdictions. [99]

User participation in fisheries management appears to work when the fisheries situation is still "rescueable," when participants have time to come up to speed on new concepts and techniques, and when information is shared between participants. The most important condition seems to be starting early enough, before resources are so scarce that management has become an exercise in frustration and none of the parties have any room to maneuver. [61]

## New tools for fisheries biodiversity

Managing fisheries for biodiversity is a job that cannot be done without tools. We need tools for people to use at all levels of governance and, because some of the players are new, we also need new tools. The tools of science must continue to be applied, especially to the challenge of understanding aquatic ecosystems better, and the well-supported meta-database FishBase, as well as other planned databases on aquatic genetic resource information, hold promise for communicating data to a very wide variety of users. But fisheries management is no longer the sole province of fisheries "professionals". [160] New stakeholders, including community groups, aboriginal groups and biodiversity planners working in the context of the CBD, need new tools.

There are other tools. Some, like the FAO Code of Conduct and the more recent FAO Technical Guidelines for Responsible Fisheries series that support Article 7 of the Code, are general, and provide a framework for crafting more specific tools on biodiversity. It is also encouraging to see that some specific tools are already appearing. The criteria developed by the Marine Stewardship Council provide one very practical example, with Principle Two being the "maintenance of the integrity of ecosystems". [35] Another example is the European Union-supported project to strengthen fisheries and biodiversity management in African, Caribbean and Pacific countries. The training program developed for this project, which is delivered largely to fisheries professionals, stresses understanding of ecosystems and aims to create awareness of biodiversity concerns among scientists and managers in developing countries ([163], www.iclarm.org). The project promotes the use of FishBase and specifically aims to stimulate new policies on biodiversity conservation and new forms of governance.

## Suggested development investments

### Protected areas

Protected areas seem to be working, and on several levels. Even very small areas have great educational value, showing local people, including fishermen, the potential richness of aquatic life and sending a strong message about human effects on ecosystems. Small protected areas allow biodiversity to be appreciated in local (not monetary) terms, and on a scale where lessons can be passed from generation to generation. Experience in several countries also shows that local support for small protected areas is contagious, so that neighbouring communities begin to create a chain of no-take or restricted fishing zones. Hence such small areas would be good development investments, as they appear to have the ability to multiply a modest initial outlay. Small protected areas in developing countries guarantee community involvement and offer the hope for an expanded network.

Choice of protected areas will have to consider the state of biological knowledge in the area, and should ideally be based on some knowledge of whether an area is a source or a sink. Developing countries are well suited to protected areas because of strong local bonds to the sea. Because of the great importance of small-scale inland fisheries, there is also a strong case to be made for investing in some pilot freshwater protected areas. However, the criteria and methods will be very different from marine areas.

Any investment in protected areas should include funding for promoting long-term monitoring.

*Relevant case studies in this report: Cook Islands, Fiji (MacKay); Philippines (Alcala).*

### Participatory management in inland waters

River communities in developing countries are prime candidates for successful participatory management (co-management) of fisheries. Freshwater fish biodiversity is affected by many outside influences, especially on habitat, so the need to interact with other sectors of societies is particularly strong.

Development investments should be made in collective action to increase local participation in fisheries management, with two caveats. First, the project team needs to have a clear understanding about boundaries between biological and social science. Biologists have to understand the role of social science in empowering communities to negotiate with the rest of society and to assist biologists in gathering information on the fisheries, as well as their own limitations in working with communities. Social scientists must in turn recognize the importance of good scientific understanding of fish populations and their response to outside pressures, and the limited interest of communities in becoming fish biologists or managers. Second, both disciplines need to become very familiar with the people on the ground, so they can identify and work with the natural leaders who will ensure project sustainability.

## Key bibliographic resources

Agardy, T. 1999. **Creating havens for marine life**. [1]

Good overview of the rationale for marine protected areas.

UN. 1995. **Agreement on Straddling and Highly Migratory Fish Stocks.** www.umn.edu/humanrts/resolutions/50/24GA1995

Kooiman, J. 1999. **Governance, and the conservation and sustainable use of aquatic genetic resources**. [87]

Summarizes current theories of governance in relation to fisheries management. Read along with Hanna [62].

Lauck *et al.* 1998. **Implementing the precautionary principle in fisheries management through marine reserves**. [90]

Makes a strong argument for "bet-hedging" in the light of incomplete knowledge of ecosystem diversity.

**Marine Stewardship Council**. www.msc.org.

The MSC is a global non-profit organization that works with fisheries management agencies to promote sustainable fisheries through a certification program. MSC's Certification Principles reflect the FAO Code of Conduct for Responsible Fisheries.

**Ramsar Convention on Wetlands**. www.ramsar.org.

The Convention on Wetlands (1971) is an intergovernmental treaty, which provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. There are presently 124 Contracting Parties to the Convention, with 1072 wetland sites designated for inclusion in the Ramsar List of Wetlands of International Importance.

Richards, L. J., and J. J. Maguire. 1998. **Recent international agreements and the precautionary approach: new directions for fisheries management science**. [133]

Discusses the main international fisheries accords and their implications for management.

Roberts, C., and J. Hawkins. 2000. **Fully-protected marine reserves: a guide**. [135]

Definitive review on marine protected areas.

Sherman, K., and A. M. Duda. 1999. **Large marine ecosystems: an emerging paradigm for fishery sustainability**. [145]

A good introduction to LMEs.

Vakily *et al.* 1997. **European Union supports project to strengthen fisheries and biodiversity management in African, Caribbean, and Pacific (ACP) countries**. [163]

Describes a large project with the specific aim of building capacity in applying biodiversity concepts to fisheries management. Contains links to obtain program materials.

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