restore the native species to the system. Tilapia population has to be controlled. The good planning and management of the 1950s must be sustained by sound management strategies. A sustainable yield of 750 t/yr must be aimed at. Productivity being good, it must be translated into optimal yield.

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Marine Fisheries, Genetic Effects and Biodiversity

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Abstract

Preservation of marine biodiversity deserves serious consideration as almost 65% of the earth's organisms (excluding insects) are marine. There is little knowledge at present on the status of marine biodiversity. However, the seas are an important source of protein for human consumption and genetic diversity is a key factor in ecosystem functioning, stability and resilience. Overfishing and destructive practices may have unalterable impact on marine biodiversity. This paper discusses measures that can be adopted to protect the most productive areas of the marine ecosystem.

Introduction

The preservation of biodiversity has become a major concern at the end of the 20th century. Increased human intervention on different ecosystems has led to the extinction of a number of higher vertebrates and an unknown, but certainly much larger, quantity of extinctions in lower taxonomic groups. However, biological diversity cannot only be viewed from the narrow perspective of species extinction. The role of species richness and abundance in ecosystem functions and the role of intraspecific genetic diversity in the struggle for survival must also be considered within this context. In this paper we explore how fisheries may affect marine biodiversity at different levels from a population genetics and species interac-

tions perspective and what actions have been or may be taken in order to preserve this vital asset.

Why Preserve Marine Biodiversity?

Preservation of biodiversity has received a great deal of attention in recent years. However, it is remarkable how little of this attention has focused on marine biodiversity. Some people believe that aquatic (mainly marine) conservation deserves less priority than terrestrial conservation. One important explanation is the general idea that the oceans host less biodiversity than land and even freshwater environments. This impression needs to be discussed.

It is true that the seas host perhaps only 20% of the total species that inhabit the earth. However, if insects, which represent 75% of all land animals, are left out, 65% of the earth's remaining organisms are marine (Upton 1992).

If we consider biodiversity at higher taxonomic levels, more phyla and even classes of living organisms are represented in the world's oceans than in terrestrial environments. Almost all (the exception being *Onychophora*) animal phyla exist in the seas, but some are exclusively marine (Norse 1993). Furthermore, if we examine biodiversity in terms of functional relationships, types of reproduction, and biochemical strategies, among others, we find an immense diversity in the marine environment. Therefore there is no real basis for the aforementioned impression.

There are other reasons why the preservation of marine biodiversity has been overlooked, e.g., the remote nature and diffficulty of monitoring and studying marine habitats and the complexity of the marine environment due to the tridimensional interchange of mass and energy. With the exception of marine birds and mammals, there is also an impression that no extinction of marine organisms has occurred in historical times, possibly due to lack of proper studies (Culotta 1994). Finally, it could also be our terrestrial orientation and a prejudice against cold blooded organisms. This last point may be exemplified by the lack of public concern regarding the virtual disappearance of the common skate (*Raja batis*) from the Irish Sea as a result of intense fishing (Brander 1988).

Loss of marine biodiversity at specific levels is difficult to quantify. The number of losses depends on the proper definition of marine environment and on how significant this environment is for the survival of specific organisms. This is particularly important for coastal habitats where human induced environmental stress is more significant. A partial list of extinct marine species includes: the Steller sea cow, *Hydyodamalis stellari*; the Atlantic gray whale, *Eschrichtius gibbosus*, the Caribbean monk seal, *Monachus tropicalus;* the sea mink, *Mustela macrodon*, the great auk, *Pinguimus impennis*; and the Labrador duck, *Camptorhynchus labrocorium* (Upton 1992). As we can see only sea birds and marine mammals are listed. Fish, invertebrates and plants, so numerous in marine environments, are notably absent. Two explanations are possible. Either extinctions in these organisms have not occurred or they have been generally overlooked. In marine and estuarine invertebrates, Carlton (1993) indicated three considerations that pointed towards the second explanation: 1) hundreds of taxa have not been reported since the 18th and 19th centuries; 2) species may have become extinct prior to their description; and 3) there has been a precipitous decline in systematics, biogeography, and natural history at the end of the 20th century, leaving too few researchers to tell the story of extinctions in the oceans.

But why is it so important to preserve marine biodiversity? There are many reasons, ecological, genetic, food and biomedical resources to name only a few. In the first place it is estimated that 19% of protein intake by humans is provided by fisheries (Botsford et al. 1997), this percentage being much higher in many island states and coastal communities. Secondly, from an ecological and genetic point of view species diversity and intraspecies genetic diversity are key factors in ecosystem functioning, stability and resilience (Chapin et al. 1997). Finally, biochemical compounds derived from marine plants, fish and invertebrates for medical applications are an active field of research today (Pérez 1993). In short, loss of biodiversity will be detrimental to the quality of human life.

The preservation of marine biodiversity is of vital significance for fisheries. Many large-scale industrial fisheries have developed in areas of high productivity, which are often characterized by low biological diversity and low stability. Such systems are readily disrupted by overfishing of just one key species. For example, juvenile herring and capelin are the main stocks of plankton feeders and the cod is the dominant predator in the Barents Sea where overexploitation of the herring is the most likely explanation for the real crisis that led to an imbalance in the state of the predator-prey relationships in this region of the northeast Atlantic Ocean. Given the lack of juvenile herring and a reduced capelin stock (as a consequence of the reduced herring stock), the growing cod stock grazed down all other available prey in the area, including its own progeny, leading to the most serious crisis in the coastal cod fisheries (Hamre 1994). Fishery induced changes in intensity of predator-prey relationships have also been documented in the

much more diverse subtropical and tropical demersal communities (Pauly 1979; Gulland 1987; Russ 1991; Mendoza et al. 1994a, 1994b). Other examples from neritic environments under heavy exploitation relate to changes in abundance of competing species such as those documented for small pelagic fishes, e.g., sardines and anchovies, in major upwelling areas where environmental variability at different spatial and temporal scales also plays a key role (Csirke 1988). In the case of small pelagic species in low diversity upwelling areas there is a more direct linkage between species abundance and environmental variability due to their relatively low trophic levels and the effect of the environment on larval dispersal and survival (Lasker 1981; Sissenwine 1984; Cury and Roy 1989). Pre-exploitation long-term biomass shifts between competing species of small pelagics have been registered from scale counts in anoxic sediments from different ecosystems (Shackleton 1987). Therefore, in these systems it is particularly difficult to separate fishery from environmental effects.

Furthermore, the development of industrial fisheries in our century has imposed serious threats to certain species of top oceanic predators such as the bluefin tuna *(Thunnus thynnus)* and oceanic sharks, thus drawing concern from diverse international bodies such the International Commission for the Conservation of Atlantic Tunas (ICCAT) and the Convention on International Trade in Endangered Species (CITES). Despite criticisms regarding the criteria used, it is noteworthy to mention the recent addition by the International Union for the Conservation of Nature (IUCN) of 118 marine fish to its Red List of endangered animals (Malakoff 1997).

Threats to Marine Biodiversity

The increase in world population by approximately 86 million people a year (Avault 1994) has provoked topographical alterations in shorelines due to the construction of new ports, airports, recreational developments, new cities, etc. Increased populations have also caused increased pollution and infestation in marine habitats.

A higher population means more mouths to feed. The harvest of fishery products from the oceans and other natural waters has peaked at about 100 million t/yr and may have started to decline (FAO 1995). At present it is estimated that approximately 50% of fish stocks are fully exploited and 22% are overexploited (Botsford et al. 1997). Following the second World War, the harvest from our oceans and fresh waters seemed to indicate that the resources were virtuallly unlimited. All that was required was increased harvesting effort concomitant with new technology (Avault 1994). How much then can our oceans yield? Based on the productivity estimated from all marine ecosystems, Ryther (1969) suggested that the harvestable fishery products from all marine waters are between 200 and 250 million t/yr. We cannot, however, harvest this total production without serious disruption of various food webs. Ryther's estimate is that the long-term sustainable harvest may be around 100 million t, which is the level recently attained. Recent work by Pauly et al. (1998) suggests that, if present trends continue, fishery induced changes in ecosystem trophic structure will inevitably lead to a collapse of many valuable fisheries. However, some experts estimate that upward of 150 million t may be sustainable (Avault 1994).

Overfishing is most often mentioned as the cause of the depletion of ocean fisheries. Increased number of fishing vessels, sonar and other sophisticated equipment, spotter planes, advanced technology as well as more efficient fishing gears have greatly increased the harvest of fish from the oceans. On the other hand, destruction of nursery areas due to aquaculture development (Pérez 1996), the elimination of mangrove swamps, the construction of new ports or airports or tourist developments, and pollution have also caused a decline in our marine fisheries. Overfishing and pollution of the aquatic environment are likely to be the primary causes of the decline in many subsistence, commercial and game fisheries. For example, Sherman (1990) analyzed 18 large marine ecosystems and cited recruitment overfishing as a major source of population collapse in three of them (Gulf of Thailand, Yellow Sea and the U.S. northeast continental shelf), while pollution was held responsible for productivity level variations in one of them (Baltic Sea). However, other important and highly stressed marine ecosystems, such as the Mediterranean Sea, the North Sea and the Black Sea were not considered in Sherman's analysis. Furthermore, Richards and Bohnsack (1990) defined the Caribbean Sea as a large marine ecosystem in crisis, mainly from intensive fishing, tourism and land development. Major changes are occurring in this area as many coral reefs have been invaded by algae due to overexploitation of herbivorous turtles and fishes as well as a demise of herbivorous sea urchin populations by disease (Pennisi 1997). Additionally, these different sources of perturbation may have genetically influenced natural fish and invertebrate populations.

The immediate result of overfishing is a decrease in absolute catch or catch per unit effort (i.e., abundance). The decrease in abundance is expected to be accompanied by an increase in growth rate, resulting from a larger amount of food being available per individual (i.e., reduced competition), as has been shown for several species of fish (Wohlfarth 1986). However, eventually fish size decreases as a result of overexploitation despite their reduced numbers. The decreased size is explained by genetic changes in populations resulting from the negative selection accompanying intensive fishing or overfishing. Fishing removes mainly the longer and more catchable animals from the breeding population. This is equivalent to selecting the smaller slower growing individuals that exhibit wary behavior as parents for the next generation. Although the species continues to exist, it may be less desirable from a human perspective and differs greatly from its original genetic condition. The long-term effects of negative selection depend on the intensity of fishing and the phenotypic variability and heritability of growth. Under these circumstances a decrease in growth may result even at low heritabilities (Wohlfarth 1986).

Fishing could also be a selective process that reduces genetic variation. It has been suggested (Smith et al. 1991) that fishing activities that concentrate on spawning populations differently remove the older and more heterozygous individuals from the virgin stock. There is an important genetic literature that demonstrates a positive correlation between heterozygosity and size, so that in a virgin population the oldest individuals will be the most heterozygous (Smith et al. 1991).

Unfortunately, only a few examples or controlled experiments actually document the real impacts of these activities. For example, the classical effects of overfishing and some selective fishing, i.e., reduced size of fish, smaller size at maturity, early maturity, and rapid early growth, appear to reverse themselves after cessation of the fishery (FAO 1993a) which is indicative of the phenotypic plasticity of these traits. Therefore, it is important to perform controlled fishing experiments on unexploited or lightly exploited populations, likely to become heavily fished, to test the null hypothesis that fishing has no effect on their genetic structures. The similar null hypothesis that should also be tested is that fishing has no effect on other components of the ecosystem with which these fished populations interact.

Another important point to consider is the possibility of lack of adaptation to rapid environmental changes. The adaptation of a natural population to its environment is a result of natural selection. This mechanism brings about adaptive changes in allelic frequencies in response to gradual changes in the environment. However, changes in aquatic environmental conditions (e.g., pollution or the introduction of exotic species) that have occurred in this century have been too rapid for the action of natural selection. Therefore, natural populations in polluted or infested waters are unlikely to have adapted to these new environments and are expected to decline as a result (Wohlfarth 1986). However, Steele (1991) considers that the natural resilience of marine systems is much higher than that of terrestrial ecosystems, hence the former would be much less affected by rapid environmental and/or man-induced perturbations.

As population abundance declines, the initial genetic impact is genetic drift (reduction in genetic variability). Due to the relatively high number of individuals, even at low population levels, in most commercially important species it is unlikely that genetic drift will become an important factor. Nevertheless, for certain species under stress the number of survivors may become so low as to create an inbreeding depression, causing a reduction in traits such as survival, fertility, growth rate, disease resistance, etc. This may be the case for certain top predators or highly vulnerable species in intensively exploited reef systems depending on the degree of self recruitment to these populations. For example, in grouper family Serranidae where protogynic hermaphroditism (individuals changing from female to male with age) and spawning aggregations with complex social structures occur (Munro 1983; Shapiro et al. 1993; Tucker et al. 1993), size selective fishing may lead to population collapse due to a shortage of males, even when fishing intensity is not too high, depending on the triggering mechanism for sex change (Russ 1991).

Measures to Preserve Marine Biodiversity

Any measures taken to preserve biodiversity will be successful only if the human population is kept within the capacity of the planet, even though this level is difficult to estimate due to social and technological changes. Also, it will be necessary to define an acceptable standard of living, especially in developed nations. Theoretically, food reserves are sufficient for actual global population, but only if there is an equitable distribution and a shift towards a vegetarian diet (Saunders et al. 1993).

The following measures seem to be necessary in order to preserve marine biodiversity and marine habitats:

BIODIVERSITY AND GENETIC MONITORING

FAO (1993a) recommended that all development proposals that

may impact aquatic habitats and aquatic organisms should incorporate in their assessments due attention to aquatic genetic resource considerations. In particular, aid-funded projects in all sectors should incorporate aquatic biodiversity considerations at the planning stage.

It will be necessary to take special care with the most productive areas of our marine ecosystems, such as: 1) estuaries that act as traps for nutrients entering from freshwater flow from land and as nursery areas for many marine species; 2) upwelling areas where deep, cold water rich in nutrients is brought to the surface leading to highly productive systems in neritic and pelagic environments; and 3) waters overlying the continental shelves (Avault 1994). This is particularly relevant considering that fisheries in these nearshore habitats require significant amounts of the available primary production and therefore present dim prospects for further development (Pauly and Christensen 1995).

ADEQUATE FISHERIES MANAGEMENT

According to FAO (1995), world fishing fleets have continously increased, reaching a total of 3.5 million boats in 1992, of which 1.2 million were industrial vessels (over 100 gross registered tons). The overcapacity of this fleet is such that economic losses in the year 1992 were estimated at approximately US$50 billion. The reduction of this fleet is a necessary part of the urgent measures needed to preserve the world's fishery resources. However, political and social constraints have been widespread limiting factors to the adoption of adequate policies. Additionally, despite timely technical advice, catch and effort restrictions are usually imposed when resources are already overexploited and hence lead to economically inefficient fishing operations and politically delicate situations for national and international management authorities. Furthermore, the overcapacity of industrial fleets from developed and formerly centrally planned economies is increasingly being exported to the biologically diverse and more fragile ecosystems of subtropical and tropical areas. These areas, in many cases, are already heavily exploited by artisanal subsistence and commercial fisheries. Unfortunately, this implies that fishing effort in many areas will continue to be excessive in the near future. Notwithstanding, this situation has led to an increased awareness of the need for better fisheries management at the national and international levels. Particularly relevant are the application of the precautionary approach in fisheries, the development by FAO of an International Code for Responsible Fishing, and the recognition of the need to adopt more conservative reference points in living marine resource management (FAO 1993b, 1995; Garcia 1993).

IMPROVED FISHING AND PROCESSING TECHNIQUES

Bycatch has been defined as "the catch of any species, regardless of sex or size, which is unintentionally harvested and which is subsequently retained or discarded because of relatively low market value or legal requirements" (Upton 1992). A recent assessment (Alverson et al. 1994) of fishery bycatch and discards estimates that overall average annual world levels are around 27 million t. Bycatch and discards cover a wide taxonomic spectrum of commercial and non-commercial marine organisms, including some endangered species. Bycatch may be separated into two components. The bycatch of small individuals of the target species which are discarded at sea and may lead to growth and recruitment overfishing and the capture of non-target species which may include highly vulnerable taxonomic groups, such as reptiles, birds and mammals. The vulnerability of these groups and others, such as sharks and rays, is mainly related to slow growth rates and low fecundities. The ecological impact, especially regarding biodiversity, of these fishing practices cannot be underestimated. Most fishing operations include a certain amount of bycatch and discards, but they are usually associated with non-selective ground fish trawling in the biologically diverse shelf areas around the world. This is especially dramatic in the tropical shrimp fisheries where bycatch and discard rates of 10 kg of fish and invertebrates per kg of shrimp landed are not unusual. The biological impoverishment of fishing grounds associated with demersal trawling has been documented in several areas (Pauly 1979; Caddy and Sharp 1986; Pauly 1988; Sainsbury 1988; Quéro and Cendrero 1996). However, the impact of trawling on macrobenthic community structure, function, and diversity has received relatively little attention (Hutchings 1990).

The best approach to reduce bycatch and discards in marine fisheries is by technological improvements and modifications of gears, as well as time and/or area restrictions on fishing activities. According to FAO (1995), short-term reductions of bycatch may be around 60% if more selective fishing gear is used. Recent examples include the international ban on large pelagic driftnets and the use of turtle excluding devices in tropical shrimp fisheries. Experimental fishing operations with separator panels also suggest that fish excluding devices may reduce bycatch in shrimp fisheries between 30% and 70% without major losses in target species (Alverson et al. 1994).

STOCK ENHANCEMENT AND HABITAT REHABILITATION

The first way to maintain biological diversity is to slow or stop its loss, but losses are nevertheless inevitable. For this reason it is necessary to restore depleted populations and degraded ecosystems. The number of restoration projects are growing as more people understand the importance of maintaining biological diversity. A variety of *in situ* and *ex situ* methods exist for recovering terrestrial and freshwater organisms. However, in the sea this is far more difficult and, even for the very few species of marine organisms that can be bred in captivity and successfully transplanted to augment existing populations or establish new ones, the costs are very high. Transplanting could also introduce harmful complications and be ineffective if the original threats are not removed (Norse 1993). Stocking with hatchery raised fish is a method of improving or restoring commercial or game fisheries in lakes, rivers, and certain coastal areas, and its use may soon increase in the latter area. However, it will be necessary to consider some experiences: the difficulty of handling wild strains in a hatchery and rearing their fry have determined the development of domestic strains, mainly in salmonids, which unfortunately are inferior to wild strains in survival, growth and quality. Thus, neither wild nor domestic strains are satisfactory for stocking in natural waters. A possible solution to this problem, at least in several species of salmonids (Wohlfarth 1986), is using interstrain crossbreeds between wild and domestic strains, for performance in natural waters, that have shown heterosis.

It is necessary to emphasize that a major goal of fisheries stock enhancement and rehabilitation should be to maintain the evolutionary potential of the population and efforts should be promoted to maintain genetic continuity of vulnerable species/populations through, for example, cryo-preservation of genetic material and the development and maintenance of aquatic reserves for natural and/or artificial propagation of species/populations prior to reintroduction (FAO 1993a).

Scientific and practical experience is very limited in relation to ecosystems. For some ecosystems, such as seagrass beds, no complete restoration success has been achieved, whereas for coral reefs there are positive examples, although they are economically costly. Salt marsh and mangrove restoration has achieved partial success at best (Norse 1993). Fishing effort limitations have proved successful in restoring abundance levels in certain multispecies demersal shelf systems, such as reported by Garcia and Demetropoulos (1986) in Cyprus. Another useful mid-term approach is through adaptative management of fishing grounds (Hilborn and Walters 1992). This should allow us to perceive the effects of fishing in a multispecies context and the resilience of different ecosystems to exploitation. Furthermore, there has been a recent drive to establish Marine Protected Areas (MPA) in several parts of the world (Schmidt 1997). The assessment of the effects of these MPAs on fisheries and related ecosystems in the near future will require much attention from the scientific community and fishery managers.

Another complication of restoration is the false sense of security generated by the impression that losses are not dangerous and restoring ecosystems or populations is possible. But this assumption is not always true; very little is known about how living systems work on land, much less at sea where our knowledge is even more limited and monitoring is more difficult.

FAO (1993a) recommended the application of genetic principles to fishery regulation and management in order to sustainably harvest the resource, to conserve the genetic structure of the impacted population, and to preserve the evolutionary potential of aquatic communities. Therefore, it is of great importance to the *in situ* conservation approach.

EDUCATION

Many fishery managers are unaware or do not accept that fishing activities may disrupt the genetic diversity of target and/or nontarget species or populations.

In this regard, FAO (1993a) recommended the production of a publication aimed at fishery managers and government agencies, outlining (in simple, non-technical language) the potential and documented genetic impacts of fishery and aquaculture activities. Fisheries managers cannot be indifferent to the threats to marine biodiversity and the detrimental effect it may have on fisheries. On the other hand, they have the expertise and resources needed to reverse the loss.

This effort should also be directed to the fishing sector, especially in tropical developing countries where destructive fishing practices in highly diverse systems are still used and regulations are difficult to enforce. For example, the utilization of explosives and active fishing gear in fragile and diverse coral reef ecosystems are highly disruptive on species composition and substrate viability (Russ 1991).

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