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Challenges of Marine Biodiversity

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Introduction

Biodiversity is a concept increasingly seen in scientific publications and on the agendas of environmental protection groups. Scientists have warned that human activities are increasingly cutting further into nature's abilities to respond to external changes by reducing the diversity of living organisms. Loss of biodiversity has reached the agendas of the global community. Initiated by the United Nations Convention on Biological diversity in Rio in 1992, the Conference of Parties of the Convention on biological diversity signed a declaration in Jakarta in 1995 (The Jakarta Mandate). The Mandate sets forth actions needed to preserve biodiversity and emphasizes the need for an integrated management approach for marine and coastal areas.

In the United States, the issue of biodiversity has entered the legislation for conservation of marine resources. Habitat loss is one of the key concepts added into the reauthorization of the United States fisheries management act (Magnuson-Stevens Conservation and Fisheries Management Act 1996). Evaluation and protection of essential marine habitat is one of the objectives of the Act. It recognizes that habitat destruction through development, pollution, and unsustainable harvest practices, might have caused reduction in productivity of the ecosystems, thus requiring stricter control of ocean resources in the future.

The concept of biodiversity is now well understood and accepted; however, the measurement of biodiversity and implications for economic analysis are not (Weitzman 1992, 1993). The extent to which biodiversity should be restored and protected is even less clear. Our food supply, production of goods, and the very oxygen we breathe all come from nature. Most people would agree that allowing all terrestrial land to become desserts through unsustainable practices is not a desirable objective. Leaving nature untouched is not a feasible option either. Society needs to be able to use nature in order to produce the goods and services that we all take for granted in our everyday lives.

Nature is highly variable. The equilibrium that appears to exist within a given ecosystem is probably only a temporary equilibrium in the evolution of life on this planet. However, the time frame in which nature works is measured in centuries and millennia, while the human planning horizon is measured in years and decades. Therefore, whether human behavior today is in fact affecting nature's ability to sustain life on earth is very difficult to determine.

Short-term changes or damages to the ecosystem can have significant economic

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effects on those living within that ecosystem; often creating economic crisis in local communities. These economic crises generally outweigh concerns for the long-term effects on the ecosystem and its resilience. The concern for biodiversity contains just as many economic issues as it does biological or philosophical. The purpose of this essay is to open the discussion of marine biodiversity within the marine economics literature, and to sort out the most important aspects of human behavior which affect marine biodiversity.

Biodiversity

Biodiversity has at least three levels: genetic, species, and ecosystem (OECD 1996). The most important level is species diversity. Genetic biodiversity refers to the differing genetic structures among the same species. This difference within a family of species is usually realized through geographical isolation where the species has adapted to different environmental circumstances. Species biodiversity is the difference among living organisms within one ecosystem. Species diversity tends to be higher in tropical areas than in temperate areas. The abundance of each species seems in general to be higher for temperate areas than for tropical areas.

An ecosystem with high biodiversity exhibits resilience, *i.e.*, being able to adapt to an external shock either by recovering to its original state or settling at a new equilibrium level. An ecosystem of low biodiversity, on the other hand, has more difficulties recovering from an external shock. Marine ecosystems are believed to have a higher level of resilience than terrestrial ecosystems (Holling, *et al.* 1995), *i.e.*, they adapt quickly to changes in environmental conditions. Species that are under great stress can quickly rebound under favorable conditions.

Some marine ecosystems exhibit less resiliency than others. The Georges Banks fishery off the coast of New England and the Canadian Atlantic fishery are good examples of the different effects over-harvesting can have on an ecosystem. Both are groundfish fisheries that were historically dependent on species like cod, haddock, pollock, and flounder (principal groundfish species), but also caught skates, dogfish, and other groundfish species (secondary species). Over-harvesting is thought, at least partially, to have played a role in the reduction of the principal groundfish species in both fisheries during the last decade. In the U.S. fishery there was an apparent shift in biomass from principle to secondary species. Decline in total biomass was also detected. The overall carrying capacity of the Georges Bank ecosystem is not believed to have changed significantly (Sherman 1994; National Research Council 1995).

In the case of the Canadian groundfish fishery off Newfoundland there is a total collapse of the principal groundfish species, and apparently, a total collapse in overall biomass. The cod fishery has been under commercial moratorium since 1992 and complete moratorium since 1994. The main cause of the collapse is thought to be overestimation of stock size in the 1980s, and consequently overharvesting of cod. The ecosystem seems to have changed as well, and contributed to the decline in principal groundfish species. However, scientists conclude that it is not possible to determine if the cause of the collapse was overfishing, overestimation of stock size, or environmental factors, or some combination (Schrank 1997).[1] Apparently, other species have not filled the gap left by the collapse of one species (cod), suggesting that the resilience of the system differs from the resilience of the Georges Bank groundfish fishery.

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[1] Sherman (1994), citing Hovgaard and Buch (1990), says that “the effects of fishing mortality on the decline of the cod are secondary to the major influence of climatic conditions over the North Atlantic.”

The effects of removing a keystone species is probably more dramatic in ecosystems with low biological diversity, such as ecosystems in the northern North Atlantic. Low biodiversity combined with abundance attracts fishers, making keystone species in the ecosystem vulnerable to overexploitation (Jakobsson 1992).

Also, marine life is highly sensitive to levels of and changes in water temperature. The boundaries of nutrient cold water and warm ocean currents create some of the most productive marine ecosystems (Bering Sea, Northeast Atlantic, Southwest Pacific). Permanent changes in ocean temperature have the potential of imposing large changes on these productive and often diverse ecosystems.

In the 1960s and 1970s, temperature and salinity change in the North Atlantic had major biological effects. In the 1960s an unusual high-pressure cell over Greenland gave rise to northerly winds over the Greenland Sea. This created a mass of cold and fresh water in the East Greenland current (Jakobsson 1992) known as the "Great Salinity Anomaly" (Dickson, *et al.* 1988). The water mass traveled through most of the North Atlantic over the next twenty-five years. Temperatures in this water mass were 0.5 to 2 degrees Celsius lower than average, and salinity anomaly were 0.1 to 0.15 units. Over the next two decades the mass of water flowed with the East Greenland current between Greenland and Iceland, down to the Atlantic and towards West Greenland and Labrador. From there the cold and low salinity water mass reached Newfoundland where it encountered the Atlantic current and went back towards the Northeast Atlantic. It passed the Faeroe Islands and finally reached the Barents Sea and Svalbard area by 1980. It is believed that this event had major negative effects on the fisheries in the areas it traveled through (Blindheim and Skjoldal 1993; Jakobsson 1992; Skjoldal, Gjosaeter, and Loeng 1992).

Threats to Biodiversity

Humans affect biodiversity both directly and indirectly. Exploitation, pollution, habitat destruction, and introduction of exotic species are some of the more serious human impacts on ecosystem functioning.

Exploitation

Harvesting has the most direct effect on the ecosystem. When millions of metric tons are taken from the ecosystem, it affects the lower and higher ends of the food chain. Fish feed on other fish as well as plankton. Birds feed on fish. However, harvesting poses no threat to the ecosystem unless the practice is destructive (*i.e.*, poison and dynamite fishing) or the resource is harvested (near) to extinction. Pauly, *et al.* (1998) examine the tropic level of global catch between 1950 and 1994. Their conclusion is that increased harvesting worldwide has reduced the mean tropic level considerably over the last forty-five years. By fishing down the marine food web, the ecosystem's diversity is threatened and the system's resilience is weakened.

Overharvesting one species within an ecosystem can cause a shift in the biomass[2] from one species to the next (Johnston and Sutinen 1996). The ecosystem might not suffer loss in resilience or species diversity. The relative abundance of some species changes within an ecosystem when one species decreases and another increases. This change might not harm the ecosystem, but it can cause great economic and social stress to the harvesting sector.

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[2] Steele (1984) defines a biomass shift as a sudden decline or collapse in a dominant resource stock, followed by an increase in another species in the same ecosystem.

An exogenous environmental event, over-exploitation, or a combination of both may cause the shift. Biodiversity loss weakens the resiliency of ecosystems, making them subject to collapse or biomass shifts. Significant biomass shifts have happened quite frequently in fisheries. Collapses of major stocks have occurred in at least ten of the world's major fisheries (Beverton, *et al.* 1984). While stock collapses have long been recognized as important, the significance of biomass shifts is a recent discovery. Many cases of stock collapse are now recognized as biomass shifts (Steele 1984). Biomass shift does not necessarily imply that the resilience of the ecosystem has been weakened, as pointed out by Sherman (1994).

One of the most renowned cases of a biomass shift followed the collapse of Peru's anchoveta stock in 1972. The fishery had been, until then, the world's largest fishery in terms of volume. The stocks of South American sardine increased substantially following the anchoveta collapse, filling the niche in the ecosystem left by the anchoveta (Patterson, Zuzunaga, and Cardenas 1992).

The biomass shift, from a high volume fishery based on anchoveta to a low volume mixed species fishery, had a significant impact on the Peruvian economy (Glantz 1979, 1980). Prior to 1972 the anchoveta fishery had been extremely successful and was an important component in the Peruvian economy. The collapse resulted in catches falling from 10.4 million metric tons (mmt) in 1971 to 4.7 mmt in 1972. When the collapse was apparent in 1973 the anchoveta industry (*i.e.,* boats and reduction plants) was nationalized in order to preserve jobs. The fleet was denationalized again in 1976. These changes in the industry caused political unrest and discontent towards the government (Glantz 1979).

What caused the biomass shift? A very strong El Niño event coincided with the collapse and biomass shift. The environmental perturbation brings warm, nutrient-poor water into an upwelling area that is normally cold and nutrient rich. The depletion of nutrients adversely affects plankton production, which is the primary food source for anchoveta larvae. A sufficiently strong El Niño can cause recruitment to fail and the stock to collapse. Heavy fishing pressure also preceded the anchoveta collapse of 1972. For five years prior to the collapse, catches had exceeded maximum sustainable yield, with especially heavy fishing on younger fish. Whether El Niño or excess fishing pressure was the dominant cause of the collapse is still not clear. Each may have been sufficient to cause the collapse, or they may have "acted in catastrophic harmony to produce a severe … dislocation of the anchoveta fishery" (Thompson 1981).

There is some evidence to suggest that trawling can have a significant effect on the diversity of benthos flora and fauna of marine ecosystems. Watling (1994) found evidence that in untrawled areas, diversity of epibenthic invertebrates, infaunal burrows and tubes, as well as diversity and abundance of young fish, was greater than in trawled areas. Jones (1992) reviewed evidence for the environmental impact of trawling on the seabed. He concludes that bottom trawling affects the environment it is used in, but the extent of the effect depends on the size of the gear and the exact physical conditions it is used in. However, the evidence is weak and further studies are needed for conclusive evidence. The United States National Research Council finds the evidence to be strong enough to identify bottom trawling as a factor in extensive change of the marine habitat (National Research Council 1995).

Pollution

Pollution, development of coastal areas, and indirect use, such as transportation (*i.e.,* ocean freighters) or tourism, may be the most serious threats to the resilience of marine ecosystems.

The oyster resource of Chesapeake Bay illustrates how anthropogenic effects have caused major changes in marine ecosystem. The native population of *Crassostrea virginicai* was once the basis of a major fishery. Reports from the 1600s and 1700s describe a great abundance of oysters; and description of reefs of oysters in the Chesapeake Bay area can be found on documents from that time (Hargis and Haven 1988). The fishery began to decline more than a century ago. With coastal development, increased pollution, and introduced disease agents, the population virtually disappeared. Oysters feed by filtering nutrition from surrounding waters. The abundance of oysters was so great that the amount of seawater that they filtered for one week came close to the total volume of water in the Chesapeake Bay. Today's abundance would require one year to filter the volume of water equal to the volume in the bay (National Research Council 1995). This causes major changes in the resilience and diversity of the ecosystem of Chesapeake Bay.

Healthy coral reefs tend to be resilient to natural shocks such as hurricanes, changes in predator/prey relationships, and changes in abundance of species that support the reef's ecosystem. Global pollution weakens coral reefs' natural resilience to such shocks. Ozone depletion in the upper atmosphere causes increased UV-B exposure, which leads to increases in algae that damage coral reefs. Direct human impacts also stress coral reefs, as for example from development and tourism in Florida and many of the popular Caribbean Islands.

Exotic Species

Transportation on the ocean is vital for the modern world economy. Generally, we do not think of freighters on the world oceans as a threat to the environment, unless they are carrying toxic cargo. However, freighters can carry organisms that are endemic in one area, and introduce them to areas where they might have either positive or negative effects in a new environment.

For example, it is believed that several species have been introduced to the Black Sea through ballast water in freighters. The most dramatic changes in Black Sea zooplankton have been in gelatinous plankton organisms (jellyfish). Between the period of 1970 to 1995, huge cyclical increases have been observed in two endemic and one introduced jellyfish: *Rhizostoma pulmo*, *Aurelia aurita*, and *Mnemiosis leidyi*. The *Mnemiosis* was probably introduced to the Black Sea through ballast water and was first observed in the early 1980s. By 1995 the *Mnemiosis* had an estimated biomass of one billion metric tons. This biomass increase is believed to have caused a collapse in the commercially fished anchovy in the Azov Sea (Zaitsev and Mamev 1997).

In 1986 in California the Chinese clam *Potamocorbula amurensis* was discovered in the San Francisco Bay. It is believed that the species was introduced to the bay by ballast water in ships. The same year that the Chinese clam was introduced, natural conditions in the San Francisco Bay changed. First, a flood caused decline in the northern Bay fauna by introducing low salinity water. After the flood, a severe drought came that led to increases in salinity above normal level. This hindered the previous fauna from recovering but favored the *Potamocorbula amurensis* clam. Now the Chinese clam makes up more than 95% of the biomass and the effects of this biomass change are expected to impact fish populations (National Research Council 1995).

Overharvesting and mismanagement of marine resources are recognized as a major factor in declining commercial fisheries around the world. Some countries have already successfully internalized the major external costs and are now in the situation where stocks are recovering (Iceland and New Zealand). Hence, the main threats to biodiversity may in the future be pollution and destruction of essential habitat, rather than exploitation or harvesting methods of fisheries resources.

Economic Aspects of Biodiversity

Why is diversity under constant threat and degradation from human activities? The ecosystem in question is usually an open access resource that is used for transportation of goods, harvesting of food and industrial raw material, and for leisure activities. The lack of strong and complete property rights to all biotic and abiotic elements of an ecosystem is the root cause of externalities and threats to biodiversity. These externalities affect a given marine ecosystem in various ways. Overharvesting of wild species in the ocean imposes higher costs on those participating in the fishery, as well as higher costs for consumers.

In addition, some resources of the marine environment, such as reefs and marine mammals, exhibit properties of public goods. Boating, swimming, whale watching, diving, and snorkeling in the marine ecosystem also have public good attributes. Pollution and site congestion are the greatest threat to these public goods, not fishing operations.

Marine mammals (*e.g.*, whales and dolphins) can be considered public goods. For many people, such animals have nonuse value. The flows of services from marine mammals are both nonrival and nonexcludable. They have an existence value to the public, and no one person can be excluded from enjoying the feeling of knowing that marine mammals exist. The magnitude of the value of marine public goods has not been quantified, but it is likely substantial. Environmental advocacy groups have raised countless sums of money to support their efforts to save whales, dolphins, seals, and turtles from human threats. National and international laws have been implemented to protect these public goods.

The extent of private use on reduction in biodiversity and loss in resilience is not well known. Perrings and Opschoor (1994) note that there are three reasons for our lack of knowledge on the externalities caused by private use of natural resource. First is the existence of discontinuities and threshold effects, second is the lack of system predictability due to uncertainty, and third is the difficulty of accounting for the functioning of life support within ecosystems.

The question is how best to deal with the loss of biodiversity in marine ecosystems, given the difficulty of quantifying the effects. Also, what implications does biodiversity have for the economic analysis of fisheries?

Fisheries economics has evolved from single species models to complicated multispecies models where interactions between species are taken into account and human behavior within the management system are quantified (Hannesson 1983; Flaaten 1991). Broadening the bioeconomic model to include ecosystem processes requires that, *inter alia*, the growth function for the bioeconomic model becomes even more complicated:

Single-species Models		Multi-species Models		Ecosystem Models
$F^i(x_i)$	$\rightarrow$	$F^i(x_1, x_2, \ldots, x_n)$	$\rightarrow$	$F^i(x_1, x_2, \ldots, x_n; \mathbf{Q}, \sigma)$

where x_i is the biomass of species i ($i = 1, \ldots, n$), $\mathbf{Q}$ is the vector of ecosystem processes, and σ measures the ecosystem's noise.

Incorporating marine ecosystem processes into a bioeconomic framework presents other challenges to the economist. As Perrings and Pearce (1994) observe, there may be a threshold where resilience breaks down and the ecosystem is irreversibly altered. In the range where resilience is not threatened, essential living organisms or physical characteristics of a marine ecosystem may have little or no economic value. The problem is fundamentally one of uncertain ecological thresholds.[3] They argue that the ecological services of biodiversity are a "layered public good" (Perrings and Pearce 1994, p. 26). That is, the external costs of biodiversity loss are both reciprocal and highly diffused, spanning multiple jurisdictions and time periods.

What instruments are appropriate for dealing with biodiversity? Is there a role for property rights? Theory suggests that giving someone the right to harvest the resource will reduce or eliminate the negative externalities caused by the race to fish.

Arnason (1990, 1998) shows that Individual Transferable Share Quotas (ITSQ) systems make the quota owner a stakeholder in the ecosystem, with an interest in the future health of the ecosystem. The harvesting rights are usually constrained to the right of harvesting a certain amount or share of a given resource. These rights are devalued if essential nursing grounds are destroyed through pollution and/or coastal development. Hence, the owner of the harvesting right has an incentive to protect the essential habitat for nursing and feeding grounds for juvenile fish. If the owner of fishing rights lobbies for protection of the habitat and reduction in pollution, his activities will have positive externalities on the public good as well, protecting recreational and leisure use of the marine environment. Arnason (1990, 1998) proposes a Minimum Information Management (MIM) approach for fisheries management, and shows that if everyone is allowed to participate in the quota market, the social optimum can be reached by maximizing the market price of all quota shares within an ecosystem.

Lauck, *et al.* (1998) notes that in the past, overfishing has occurred before clear signals have appeared to the fisheries manager. Hence, imperfect information, natural uncertainty, and pure speculation might lead a fishery over the biological thresholds needed to maintain the resilience of the ecosystem. This could happen if the available information to participants in the market were not timely enough to detect overfishing or destruction of natural habitat, resulting in a collapse of the ecosystem.

Perring and Pearce (1994) suggest there is a role for standards, where the standard is based not on economic considerations, but on ethics. They perceive the Precautionary Principle as essentially an ethical judgment about the appropriate way for society to respond to such risks to the global environment. According to Myers and Mertz (1998), such standards could include allowing fish to spawn at least once, or by making a safety margin by having the difference in age of maturity and the age of selection at harvest very small. The precautionary principle also could be implemented by using marine reserves as an important part of fisheries management (Lauck, *et al.* 1998).

Political implementation of the Precautionary Principle may be difficult. Often it means foregoing opportunities in order to avoid an event that *might* happen. Such an argument is not likely to persuade the users of the fisheries resource. The Precautionary Principle therefore needs widespread global recognition and support to be meaningful for fisheries management. Increasing globalization in trade with fisheries products between nations with different ethical judgments on how to utilize resources adds considerable difficulties in applying the Precautionary Principle.

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[3] Johnston and Sutinen (1996) examine this problem in the case of biomass shifts and collapse.

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