



AQUATIC BIODIVERSITY CONSERVATION:

A Review of Current
Issues and Efforts

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Aquatic Biodiversity Conservation:

A Review of Current Issues and Efforts

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Executive Summary

Biodiversity, the genetic library maintained by natural ecosystems, is the basic biotic resource that sustains all human life-support systems. From algae to humankind, biodiversity embodies the unique genetic blueprint of every living organism on this planet, *and* the environment in which that organism has evolved and become adapted. Having recognized the importance of biodiversity for survival, humanity has now undertaken the crucial task of its conservation.

The purposes of this paper are to highlight the wide array of aquatic life forms and habitats that exist and to document some of the destructive patterns causing their demise. An attempt is also made to prioritize target conservation environments and taxonomic units and to outline strategies and mechanisms presently being developed to address problems associated with these environments.

Fish are the fifth largest agricultural resource and are the primary source of protein for over 1 billion people, yet aquatic biodiversity remains a neglected issue. Recent estimates suggest that worldwide, 20% of all freshwater species are either extinct, endangered, or vulnerable. Our grasp of tropical aquatic diversity is woefully incomplete and likely the last major void in global knowledge of vertebrate diversity.

Humans have been a significant evolutionary force in every ecosystem they inhabit. Due to extensive intervention, mangrove and coral-reef degradation is affecting coastal productivity in many tropical countries. These disturbances directly or indirectly alter community dynamics in ways potentially detrimental to native species and populations. The six major disturbances causing aquatic species' decline and potential extinction are habitat loss and degradation, over-exploitation, the spread of exotic species, secondary extinctions, pollution, and climate change. All of these disturbances, either singly or in various combinations, accelerate environmental change and, in so doing, modify community composition, structure, and function by reducing or eliminating the abundance of those species not adapted to the altered environment. To minimize the probability of species bankruptcy, clear objectives for biodiversity conservation must be formulated.

Habitat Conservation Measures

Conservation policies must take into account that aquatic species are the only remaining non-domesticated food resource of major significance. Efforts to conserve terrestrial wildlife have primarily focused on ecosystem-level preservation, and so they should for aquatic wildlife as well. However, because aquatic environments are under intense pressure to provide food, pharmaceuticals, and industrial products to an ever-increasing human population, even greater diligence is required if aquatic communities, species, populations, and their habitat are to survive. Safeguarding aquatic biodiversity demands that additional measures be taken to control external stressors such as pollution, agricultural runoff, and deforestation.

The ecosystem-level approach however, may not afford taxonomic units on the brink of extinction the immediate conservation assurance necessary. Under such circumstances, *ex-situ* measures, i.e., preservation of genetic resources outside of their natural habitat, are needed to ensure that the organisms' genetic fabric is secured. Institutions conducting research on *ex-situ* conservation (either live specimens or cryopreserved) include zoos, aquaria, museums, universities, and private fish enthusiasts. Rapid implementation of *ex-situ* measures is particularly critical for species of traditional economic importance. However, conservation techniques should not be limited to species of potential economic value alone, otherwise functional diversity may be compromised in the future. In less critical situations, *in-situ* community-management strategies that target multispecies assemblages are needed to complement gene-level conservation tactics.

To effectively conserve aquatic resources, it is essential that immediate focus be placed on *taxonomic hotspots* and highly productive environments susceptible to degradation: coastal, riverine, estuarine, coral reefs, and mangrove environments. Within these environments, the selection of which level of biodiversity to target and which approach to take will depend on the state of the fishery in general, or the species and their populations in particular.

When coastal nations expanded their territorial waters to the 200-mile limit, they gained the legal jurisdiction and management responsibility for over 85% of the world's fishery resources. The Large Marine Ecosystems (LME) approach builds on the foundations of territorial expansion and targets 49 unique marine and coastal environments. The LME approach recognizes that the sea consists of fairly distinct regions within which physical conditions, biological communities, and fish stocks are best managed as a regional ecological unit.

The five-tier approach recognizes the watershed as the fundamental conservation unit and was developed for freshwater ecosystems characterized with high endemism and rapid species loss. From an in-depth inventory of the watershed, clusters of species known to routinely share restricted geographic ranges and deemed to be endangered, threatened, or rapidly declining, are identified. These inventories are conducted within targeted watersheds on management units that are usually 50 km². The process is then expanded to entire watersheds within a region and is followed by the integration of several key watersheds into a regional approach. Both the LME and five-tier approaches promote ecosystem integrity and stock-management strategies that target multispecies assemblages.

Genetic Conservation Measures

Although *in-situ* conservation of wild gene pools and their ecological support systems will remain vital, *ex-situ* conservation is an additional precautionary measure that must not be overlooked. *Ex-situ* strategies, however, should never be seen as an alternative to maintenance of aquatic ecosystem integrity. As reservoirs of genetic resources, cryopreserved materials represent a *genetic snapshot* of local populations at a specific time in evolution and may help breeders to deal with both present and future crises. A major benefit of *ex-situ* conservation is that cryopreserved genetic resources may serve in evolutionary, reproductive, and developmental biology research. In addition, such material may be used to advance spawning coordination and to overcome constraints associated with the movement of fresh sperm.

In an effort to produce all-purpose breeds that yield well across a variety of environments, many fish-breeding strategies emphasize adaptation to intensive management and disease resistance, and ignore genetic-environment (GE) interactions. Genetic variability may be promoted through selective diversification, a breeding regime wherein strong (GE) interactions are recognized as a key component of breed development. Breeds developed from such a strategy may serve as a living library to accommodate future changes in consumer preferences, economics, husbandry techniques, and national or regional genetic improvement strategies. Such a breeding strategy is a compromise between the needs for increased yield and for genetic biodiversity conservation.

Fisheries and aquaculture geneticists are now using a broad range of highly sophisticated technologies to answer questions pertaining to fish and shellfish population genetics and evolutionary lineages. Molecular tools are now enabling scientists to effectively pinpoint genetic dissimilarities among and between

different levels of biodiversity and to monitor fluctuations over time and space. With the advent of these tools, significant progress in fisheries management and conservation is expected. With respect to the use of the species complex as a conservation unit, however, several questions remain unanswered. One alternative gaining greater attention is the evolutionary significant unit (ESU) defined as a reproductively isolated population that has undeniably contributed to the evolution of the species. Assigning ESU status, however, has proven problematic because statistical significance does not imply evolutionary significance, and genetic differences may not equate to genetic distinctness. Due to our lack of empirical knowledge, more extensive research on ESU and genetic stock structures is needed.

Ex-situ conservation emphasis must be placed on the application of the most efficient and cost-effective techniques relating to the conservation of ESUs. How and where the lines are drawn in the process of saving the maximum amount of effective biodiversity in aquatic ecosystems must be determined. In aquaculture, *ex-situ* technologies must be developed in conjunction with husbandry improvements, environmental impact awareness, and ecological technologies to create sustainable production systems.

A balance must be struck between conservation ethic and utilitarian concern. Target criteria such as ecosystem function, commercial importance, and traditional values must be defined. If management is ever to be successful, it is imperative that both *in-situ* and *ex-situ* conservation techniques be incorporated into a conservation framework that acknowledges adaptive co-management strategies. Unless fishers themselves are integrated into the whole decision making process, research will never have the desired impact on aquatic biodiversity conservation.

Biodiversity Conservation and Management

The question of aquatic biodiversity conservation rests with resource management. If stocks were sustainably managed and habitats preserved, conservation would likely not be as grave an issue — the crisis response. Although stock-management strategies worldwide vary almost as much as do cultures, two contrasting models emerge: western and traditional.

In many regions of the world, fisheries management continues to be based upon the fundamental principle of common property under which no one individual can control the resource. Marine fisheries in Western societies are perhaps the

last major resource to have been exploited under open access regimes. Society in general, benefits under a common property regime as long as the sought after resource remains plentiful and its exploitation remains economically viable. One of the major problems associated with common property is that fishers inevitably end up competing against one another for the same fish, which ultimately leads to excess effort as individuals aspire to increase their share of the limited resource. Within countries adhering to common property principles, attempts to curb over-exploitation have ranged from limited entry through quotas to numerous restrictions on gear, species, and season. Regrettably, these efforts have not often succeeded because they inadequately address the problems inherent to common property regimes.

In contrast, many aquatic resources are traditionally managed under community-based forms of sea tenure or self government, wherein access to coastal and inland waters is determined by society and founded on the social organization and cultural dimensions of the community. Within a sea-tenure framework, user rights to specific regions, species, gear, and seasons are allocated to individuals, families, or clans usually by an elder or community leader. Many traditional conservation strategies were designed under low population pressure and based on sound ecological principles. As population density has increased, in many cases the pressure has exceeded the conservation limits these measures were designed to achieve. Social change and the advent of commercial fishing opportunities are also causing many of the traditional conservation structures and management approaches to break down.

From these contrasting strategies, three fundamental issues emerge: property rights, the lack of synergy between authorities and fishers, and the breakdown of traditional management systems. Greater endorsement of community-based approaches to address these issues is beginning to surface as the option of co-management gains legitimacy and as fiscal restraints grow more severe. Because aquatic ecosystems have multiple uses, management objectives must aim to minimize use conflicts, maintain ecosystem health, promote scientific understanding, and increasingly support more people. These objectives must be defined by consensus between fishers, local communities, researchers, and government officials. To meet these objectives effectively, co-management strategies must be implemented within a legally binding framework, thus ensuring that rights over resource use and conservation are protected.

Recommendations

It is crucial that appropriate measures be taken to reduce continued habitat loss. The challenge of modifying, and if necessary, suspending or abolishing destructive harvesting practices must be met. It is also imperative that policies that inadvertently create the incentive for fishers to high-grade be eliminated. Furthermore, management strategies and gear technologies must be developed such that bycatch levels are significantly reduced. In an effort to achieve these conservation objectives, an international advisory committee could be commissioned to approve project and loan applications on the condition that applicant nations abide by and enforce a set of provisions and a standard code of practices pertaining specifically to biodiversity conservation.

If the LME and five-tier approaches are acknowledged as appropriate *in-situ* conservation initiatives, then specific measures must be taken to ensure that the political willingness to collaborate in sustainable management be fostered between those nations sharing either an LME or a watershed. Because of the complexities associated with regional collaboration, international bodies such as those within the Consultative Group on International Agricultural Research (CGIAR) and the Food and Agricultural Organization of the United Nations (FAO), could negotiate agreements to seek appropriate solutions and sound management strategies amenable to all parties. In terms of required research, several topics emerge: the impact of continued harvesting on population dynamics and demographics, the ecological role of lesser known taxonomic units, the functional redundancy – population resilience phenomenon, endangered marine species status re-definition, greater emphasis on selective diversification in breeding strategies, and increased evidence and support for the ESU concept as the conservation unit.

Introduction

Biodiversity, the genetic library maintained by natural ecosystems (Ehrlich and Wilson 1991), is the basic biotic resource that sustains all human life-support systems (Kim 1993). From algae to humankind, biodiversity embodies the unique genetic blueprint of every living organism on this planet, and the environment in which that organism has evolved and become adapted. Biodiversity is divided into five hierarchical levels: (1) ecosystems, (2) communities, (3) species, (4) populations, and (5) genes (Soulé 1991). Each level is further sub-divided into three primary components - composition, structure, and function — all organized into nested sets (Walker 1992 in Kim 1993). The key word is nested because it underlines the complexity and interconnectedness between and within levels of biodiversity.

"Biological diversity is defined as the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems, and the ecological complexes of which they are part, this includes diversity within species, between species, and ecosystems" (UNCED 1992)

Having recognized the importance of biodiversity conservation for survival, humanity has now undertaken the crucial task of preserving it. The purpose of this paper is to highlight the exhaustive array of aquatic life forms and habitats that exist, and to document some of the destructive patterns causing their demise. An attempt is also made to prioritize target conservation environments and taxonomic units, to outline strategies and mechanisms presently being developed to address problems associated with these environments, and to recommend potential guidelines that may help to redress previous environmental wrongs (Larkin 1992).

The recently ratified Biodiversity Convention is expected to significantly improve how humanity manages, exploits, and trades the Earth's resource endowment in the 21st Century. Under this accord, countries have pledged to rationally utilize and conserve our finite resource base such that future generations gain equal

access to the genes, populations, species, communities, and ecosystems that define the biodiversity hierarchy we currently enjoy — the inter-generational equity principle

Although biodiversity is shared between terrestrial and aquatic environments, unfortunately, aquatic (freshwater and marine) biodiversity has been grossly neglected. The international conservation agenda has, thus far, centred primarily around large, charismatic terrestrial species and their habitats (Ray and Grassle 1991). Our preoccupation with terrestrial environments can be partly attributed to the fact that, as terrestrial beings, we have a tendency to focus on our immediate surroundings and to disregard the impact of our activities on distant aquatic environments. Recently however, it has become blatantly obvious that we can no longer afford to neglect the aquatic environment.

Taxonomic Diversity

"Fish are the oldest, largest, and most diverse living vertebrates on Earth, outnumbering all other vertebrate species combined" (Cairns and Lackey 1992). Researchers are only beginning to grasp how diverse aquatic systems really are. Recent data suggest that the diversity of life, primarily of invertebrates, teeming in the deep seas and abyssal zones may be several orders of magnitude greater than previously anticipated (Holloway 1994, Grassle et al 1991). In freshwater environments, 100 new fish species are discovered annually (Page and Burr 1991 in Allan and Flecker 1993). Through research in taxonomy and genetics, the distinctiveness of marine organisms is becoming apparent. More than half of the Earth's vertebrates are fish (Warren and Burr 1994) and this exhaustive list

With 33 phyla of which 13 are endemic, the marine environment is likely the most diverse biome on Earth. In comparison, there are only 11 terrestrial phyla, 1 is endemic (Biagi 1994, Ray and Grassle 1991). Because of the relative absence of temporal and spatial disturbances in marine systems, the time frame associated with speciation was prolonged, and evolutionary differentiation favoured higher taxonomic levels (Cognetti and Curini-Galletti 1993, Ray 1991). Pisces alone comprises 3 living classes, 50 orders, 445 families, and 25,000 species, and, recent estimates suggest that there are approximately 5000 more species to be discovered, named, and classified (McAllister, pers. comm., Ray 1991).

is by no means complete. In fact, present knowledge and experience is largely based on temperate aquatic vertebrates and their ecologies. Our grasp of tropical aquatic diversity is "woefully incomplete and likely the last major void in global knowledge of vertebrate diversity" (Allan and Flecker 1993)

Large tropical rivers are several times more diverse than their temperate counterparts. Whereas 2000–3000 fish species are found in the Amazon River, only 700 species have been described in temperate North America, and 177 in Canadian inland waters (Welcomme 1990, Scott and Crossman 1973 in Allan and Flecker 1993). Prolific speciation in freshwaters has been largely due to greater geographic isolation and habitat heterogeneity, which influence gene-flow patterns throughout a species' given populations (Ryman et al 1993, Ray 1991). Gene-flow patterns in freshwaters are significantly affected by water-body dimensions because significant correlation has been found between the rate of increase in species richness and increasing surface area (Welcomme 1979 in Allan and Flecker 1993). Although freshwater systems represent less than 1% of the Earth's aquatic resources, 41% of bony fish (teleosts) evolved in freshwater environments (Cohen 1970 in Upton 1992)

Biodiversity Lost

Aquatic biodiversity is under severe stress. Estimates suggest that worldwide, 20% of all freshwater species are either extinct, endangered, or vulnerable (Moyle and Leidy 1992). These sub-species and populations may confer species resilience to disturbance and catastrophe. If this resilience is significantly weakened due to continued losses at these levels, a greater number of species will become threatened or endangered. In addition, the genetic contribution to the species as a whole, attributable to these sub-species and smaller populations, may be very substantial, as observed in Pacific salmon (Allendorf and Utter 1979)

In North America, 28% of freshwater fish species are in trouble with "103 species and sub-species endangered, 114 threatened, and 147 deserving special concern" (Williams et al 1989), primarily due to habitat loss (73%) and introduced species (68%) (Hughes and Noss 1992). In California, more fish species (68%) are in some state of peril than are healthy (Moyle and Yoshiyama 1994)

Under the US Endangered Species Act (ESA), most listed aquatic species are either of riverine or estuarine origin. These aquatic ecosystems are especially vulnerable because of their proximity to human development (Huntsman 1994). In addition, typical riverine populations are smaller and more isolated than their marine counterparts and, consequently, more vulnerable (Ryman et al. 1993). One cannot ignore the fact, however, that 39 marine species are at dangerously low levels due to over-exploitation and in dire need of population status re-evaluation (Huntsman 1994).

From a scientific viewpoint, the whole question of marine finfish endangerment is controversial due to the lack of geographic isolation in many marine environments. It is argued that sophisticated larval dispersal mechanisms, characteristic of many marine species, promote widespread gene-flow patterns, ultimately resulting in range expansion, thus reducing the threat of species extinction (Huntsman 1994, Ryman et al. 1993). In addition, because of the sheer vastness of the marine environment, people have difficulty in perceiving that marine organisms can become endangered. More specifically, however, listing marine finfish may have serious management repercussions on industrial fisheries. Under present legislation, if endangered species became bycatch victims, even major fisheries with abundant stocks would be shut, thus, directly affecting the livelihood of those dependent on the fishery (Huntsman 1994).

Coastal ecosystem health is directly linked to the productivity of the extensive mangroves, coral reefs, estuaries, lagoons, bays, and sea

In their review of Southeast Asian coral reefs, Wilkinson et al. (1993) estimate that 60% of the coral reefs have been either destroyed or severely degraded. Within the reef-rich archipelagic nations of the Philippines and Indonesia, studies indicate that reefs are threatened due to hazardous and destructive harvesting practices such as dynamite and muro-ami fishing (Lundin and Linden 1993). In the Gulf of Thailand, coral reefs are in serious jeopardy due to organic and inorganic pollution and sedimentation stemming primarily from the Pattaya River (Sudara and Nateekarnchanalop 1988 in Lundin and Linden 1993). On the southern and western coasts of Sri Lanka, coral reefs are disappearing at an estimated rate of 10% annually (Rajasuriya 1993). In their 14 Caribbean-nation study, Smith and Ogden (1993) found that almost 60% of the reef areas were damaged due primarily to hurricanes, pollution, sedimentation, and destructive fishing practices.

lochs typical of these environments (Pearce 1995, Martsubroto and Naamin 1977 in Lundin and Linden 1993) However, as a result of human intervention, mangroves and coral reefs are suffering extensive degradation Mangroves are marine tidal forests that protect coastal communities from floods and provide aquatic species with critical refuge Due to indiscriminate extraction for charcoal making and expanded aquaculture (particularly shrimp farming), however, mangroves have been markedly reduced (Thia-Eng and Scura 1992 in Lundin and Linden 1993) In Southeast Asia, 27% of Thailand's mangrove area has been lost, in Malaysia 20%, in the Philippines 45%, and on the Indonesian islands of Java 70%, Sulawesi 49%, and Sumatra 36% (Avault 1994) In the Saudi Arabian Gulf, only 4 km² of mangrove remain due to war and unrestricted coastal development (Price and Sheppard 1991 in Cognetti and Curini-Galletti 1993) The rate at which coral reefs are vanishing is also very disturbing The consequences of widespread mangrove and coral-reef destruction will eventually be measured in lost aquatic biodiversity

Scope and Importance

Humanity has become highly dependent on aquatic diversity for survival According to Seshu et al (1994) "fish are the fifth largest agricultural resource accounting for 7.5% of global food production and represent the primary source of protein for over 1 billion people" Total aquatic food production is estimated at 104 million metric tonnes (Born et al 1994) Of the 253 million tonnes of animal protein consumed by humans in 1988, marine fisheries contributed most, with 65 million tonnes followed by cattle with 50 million tonnes (Hinds 1992) During the 1980s, the annual per capita consumption of fish and seafood rose 16.8% (FAO 1991) This trend will continue as incomes continue to rise in many developing countries, particularly in Asia (Born et al 1994) Based on current consumption patterns and population growth rates, an additional 19 and 100 million tonnes will be required annually by the years 2000 and 2025, respectively (Seshu et al 1994) Increasing production, however, will require that sources be diversified as capture fishery levels of many traditionally valuable species have either peaked or are declining (Avault 1994, Becker 1992)

As stock depletion continues, pressure on aquaculture to maintain food security will escalate

"Fisheries worldwide are in transition from less hunting to more farming of fish" (Larkin 1993)

Aquaculture will only realize its full potential, however, if sufficient attention is paid to the genetic, biological, environmental, cultural, and socio-political milieu in which venture initiation or expansion is

proposed. If aquaculture production is to "keep pace with demographic projections" it is estimated that 65 million tonnes will be required by 2025 (New 1991 in Born et al 1994)

Based on production figures from 1975 to 1989, the aquaculture industry is growing at an annual rate of 6.4% with finfish (primarily Chinese carps, trouts and salmons, tilapias, and catfishes) representing more than 50% of the total 14 million tonnes produced (Born et al 1994)

If future aquaculture production objectives are to be met, fish farming systems will have to become progressively more intensive and technology oriented. Although fish genetics remains an unexplored *black box* (Larkin 1992), the future role of breeders is expected to become increasingly important (Seshu et al 1994). Experience gained in crop- and animal-breeding programs confirms that for breeders to raise yield, reduce feed conversion ratios, improve body and flesh characteristics, increase stress and disease tolerance, and enhance prolific reproductive traits, it is imperative that they have at their disposal a library of native germplasm from which to select. Consequently, it is absolutely essential that aquatic genetic biodiversity be conserved.

Inextricably linked to the conservation of aquatic genetic resources is habitat preservation. It is widely recognized that conserving the spawning and rearing grounds in which aquatic organisms have evolved and adapted over geological time, along with the genetic diversity that enables them to do so, is the best policy for future generations. Furthermore, not only is it critical to conserve habitats *per se*, but within-habitat heterogeneity is also compulsory because the availability of alternative niches enables species and their populations to seek out environments to which they may be more genetically suited. These alternative niches provide shelter from predators as well as a variety of feeding and mating grounds for a wider range of competing species. Habitat heterogeneity allows otherwise incompatible species to coexist (Benson and Magnuson 1992). How species are distributed along this continuum of habitats will influence both the intensity and frequency of ecological disturbances (Sousa 1984 in Benson and Magnuson 1992).

Natural and anthropogenic habitat disturbances directly and indirectly alter community composition, structure, and function in ways potentially detrimental to native species and their populations (Reice 1994) Once disturbed, ecosystems are recolonized either by regrowth of remnant residents, recruitment from distant communities, or migration from contiguous environments (Reice 1994) In addition, it is argued that as disturbance intensity increases, species diversity declines, i.e., the number of species decreases and the number of tolerant individuals, often of opportunistic species characterized with high reproductive rates and low genetic variability, increases (Cognetti and Curini-Galletti 1993) To effectively minimize the risk of genetic erosion, both gene- and ecosystem-level conservation strategies must be developed synergistically

Reconstituted populations derived from severely depleted remnants, however, may be genetically inferior as a result of inbreeding depression (Cognetti and Curini-Galletti 1993) or may no longer fulfil their ecological role, eventually causing ecosystem collapse (Upton 1992)

Destructive Patterns

"Humans have been a significant evolutionary force in every ecosystem they inhabit and have been responsible for many genetic changes in both domestic and wild species" (Lester 1992) Serious consequences arise from human settlement Allan and Flecker

(1993) have identified six major anthropogenic disturbances that accelerate aquatic species decline and potential extinction habitat loss and degradation, over-exploitation, the spread of introduced species, secondary extinctions, pollution, and climate change

Half the world's population is estimated to live in coastal regions (Grassle et al 1990) and over 70% in Southeast Asia specifically (Thia-Eng and Scura 1992)

Habitat Loss and Degradation

Terrestrial development can directly and indirectly modify near and distant aquatic environments with immediate and long-term impacts on aquatic communities These developments include

- (a) impacts of fishing gear and methods such as trawlers, explosives, and toxins,
- (b) competition for water as a result of irrigation and urban waterworks projects,
- (c) channelization, nutrient-flow disruptions, and migratory route obstruction by hydroelectric dams,
- (d) wetland drainage and conversion,

The impact of such disturbances on native aquatic populations include

- *declines in specialized taxa and native species,*
- *fewer habitat and trophic specialists and increased generalists,*
- *increased introduction of exotics and greater incidence of disease,*
- *reduced total abundance, and*
- *declines in demographic indicators, such as number of large, mature individuals, and fewer size and age classes* (Fausch et al 1990, Margalef 1963 in Hughes and Noss 1992)

- (e) increased siltation and agricultural run-off due to deforestation,
- (f) salinity fluctuations in estuaries and inland seas with limited buffering capacities, and
- (g) introduction of exotics (e.g., carps and zebra mussels)

"Typically fishes are more strongly affected by environmental fluctuations" (Allendorf et al 1987 in Ryman et al 1993) and consequently, changes in temperature, depth, current velocity, substrate size, sediment deposition rate, salinity, pH, dissolved oxygen, nutrient availability, and heavy metal concentrations may be highly detrimental to aquatic populations. How ecosystems respond to disturbances can be complex and chaotic (Wilson et al 1994). Nonetheless, all levels of biodiversity can be adversely affected.

Over-Exploitation

Commercial over-exploitation is one of the leading causes of marine biodiversity loss (Holloway 1994). Depleting stocks of valuable species accelerates shifts in community assemblages, often causing species of less economic value to emerge and dominate populations (Sherman 1989 in Alexander 1993). Under the assumption that oceans were an "inexhaustible cornucopia of resources" (Regier 1995), industry and small-scale owners over-capitalized on trawl fleets during the 1960s and 1970s, and eventually depleted numerous stocks in an effort to recoup investments (Bailey 1988). In the end, many fisherfolk suffered significant economic losses and declines in standards of living.

Continuous over harvesting seriously alters population demographics and life history traits, e.g., selection pressure associated with intensive harvesting can induce "increased reproductive effort at young ages, resulting in early maturity, shorter life spans, smaller sizes, and semelparity (singly reproductive episodes)" (NMFS 1990 in Upton 1992)

In addition to greed, resource over-exploitation is poverty driven. In many developing countries where coastal communities are the *poorest of the poor* with little or no economic opportunity, over-exploitation remains a serious problem. Authorities in developing countries are often unable to restrict fishing effort, and as a result, fish stocks continue to be depleted and habitats irreparably damaged.

Due to lack of alternative employment, many displaced farmers take up fishing and often resort to such non-target specific practices as dynamite and cyanide fishing, which cause enormous habitat damage. Circumstances are often such that long-term conservation ethic and commitment are superseded by short-term survival strategies and, consequently, "many small-scale fishers utilize whatever means possible to harvest as many fish as possible" (Kuperan and Abdullah 1994, Pomeroy 1991). As populations in many developing countries continue to increase, so will the pressure on depleted stocks.

Bycatch and discards as a consequence of many fishing practices may have detrimental effects on valuable species assemblages because the ecological impact of shifts in community composition and of differential predator and scavenger survival in bycatch remains unknown. It is therefore extremely critical that we carefully determine catch composition in mixed stock fisheries (Larkin, pers. comm.)

In Southeast Asia and Africa, it is estimated that 65% and 84% of the total catch respectively, is caught by small-scale coastal-marine and inland fishers (Willman 1983 in Hviding and Jul-Larsen 1993)

*In the pre-shrimp era of coastal Malaysia, the fishery was dominated by five important families. All showed severe declines due to discarding once shrimp trawling commenced (Pauly and Neal 1985 in Alverson et al. 1994). The Gulf of Alaska fishery of the 1960s was dominated by flatfish species, King and Tanner crabs (*Paralithodes* spp and *Chionoecetes* spp), Pacific cod (*Gadus macrocephalus*), and Pacific ocean perch (*Sebastes* spp). By the 1970s the Pacific pollock (*Theragra chalcogramma*) dominated. The ocean perch catch fell from 36.8 to 3.9 kg/rawl hour (Ronholt et al. 1978 in Alverson et al. 1994)*

The Spread of Exotic Species

The principal sources of exotic species of fish include escapees from intensive aquaculture systems, and intentional releases from sea ranches, and national, local, and private restocking programs, all of which are gaining

Extinction is defined here as local population extinction within the exotic species' confined range

greater production importance. Of equal importance are recent efforts in biological control (e.g., grass carps), escapees from the ornamental fish trade, the movement of organisms as a result of dumping of ballast water from ships, and the impact of these foreign organisms (e.g., zebra mussels) on the environment and resident species. As enhancement activities increasingly rely on hatchery-reared and genetically (even transgenically) manipulated breeding and production stocks, the potential for extinction, evolution, and hybridization of native fish populations is only expected to increase.

Species and populations most prone to extinction due to introductions are those confined within closed or semi-closed water bodies, particularly when high trophic level predators or efficient competitors are introduced (Lester 1992). If exotic species survive until the reproductive stage and successfully interbreed with native resident populations, the local genetic pool is expected to change. Both the rate and magnitude of change vary and depend on how genetically divergent the introduced and resident species are (Lester 1992). In addition, inter- or intra-specific hybridization can significantly alter community dynamics. Recent findings indicate that "many aquatic organisms, particularly teleost fishes, have unusual capabilities to hybridize" (Campton 1987, 1990 in Ryman et al. 1993), and consequently, exotic species may jeopardize the genetic integrity of native stock. Although hybridization may not cause individual genes to be lost *per se*, rearranging gene complexes may cause beneficial genotypes, that selection has favoured over time, to go astray (Hindar et al. 1990 in Ryman et al. 1993). This is particularly critical in freshwater species adapted to specific niches. Further, if exotic species outcompete native species for resources or feeding and mating grounds, they can permanently disrupt native population dynamics. Lastly, increased predation by foreign species, e.g., lamprey (*Pteromyzon marinus*), may threaten native communities.

Stock identification and cataloguing by means of genetic differentiation are important tools used in the management of valuable anadromous species such as salmon. Strong homing instincts guiding salmon to their natal streams have led to

the creation of many tempo-spatially isolated populations. These fish are harvested at high sea as mixed stocks on their return to native spawning beds. Determining mixed stock composition has proven a difficult challenge using conventional tagging methods, and this has contributed to the inadvertent over-harvesting of sensitive stocks as the healthier runs are pursued. Genetic sorting of distinct stocks and strains by means of specific genetic markers should lead to improved harvest calendars whereby fishing pressure may be scheduled to times when the more robust stocks make up the majority of the run (Utter and Ryman 1993).

Molecular studies are also being conducted in an effort to understand interaction dynamics between hatchery-reared exotic species and native fish populations and to determine the impact of

such interactions on the genetic integrity of wild stocks. Traditional quantitative measures of aquatic biodiversity often overlook important qualitative differences in structure, function, and species sensitivities to introductions (Hughes and Noss 1992, Upton 1992). Research is only beginning to unravel the potential consequences of non-native fish on wild, locally adapted populations.

*Genetic erosion due to interbreeding with exotic species is a complex issue. The depression effect of interbreeding native stocks with genetically "homogenized" hatchery fish on specific adaptive gene complexes may be consequential (Stahl 1987 in Utter et al 1993). One example is that of the Californian coho salmon (*Oncorhynchus kisutch*) whose populations have plummeted by 94% since 1940 (Brown et al 1994). This decline has been partly attributed to the deterioration of native stock genetic integrity. How meddling introduced stocks have become is reflected by estimates that 57% of the salmon returning to California are of hatchery origin and only 16% are wild (Brown et al 1994). Because these native coho populations are the most southern stocks, their genetic adaptation to warm water is of ecological and evolutionary significance because this tolerance may become an important trait should global warming trends continue.*

Secondary Extinctions

As species coevolve in assemblages, intricate food chains are formed. When ecosystems are made to bear inordinate levels of stress, links in the chain may become extinct or threatened, often adversely affecting upper trophic levels to the point where their own survival becomes endangered. This cascading effect

may cause ecosystem destabilization and consequently, the process of secondary extinction is of serious concern in aquatic systems, particularly where strong, varied, and redundant trophic-nutrient interactions confer community stability and resilience. For example, when upper trophic level populations are overexploited, a rapid proliferation of zooplankton may be observed, thus precipitating a decline in phytoplankton abundance and diversity. Phytoplankton productivity then becomes a function of generalist zooplanktivore abundance as opposed to nutrient availability, thus potentially increasing the likelihood of modifying community structure and composition (Larkin, pers. comm.). At this point, exogenous factors trigger ecosystem stability and resilience collapse remains obscure.

Pollution

Pollution is a major problem to all living organisms. Suffice to say, however, that aquatic systems have served as major pollution sinks likely since the dawn of humankind. Fluctuations in physical, chemical, and thermal properties are detrimental to aquatic systems and their biota because they can hasten the demise of sensitive, ecologically significant and traditionally valuable species. This is particularly true for marine systems with generally constant chemico-physical properties (Cognetti and Curini-Galletti 1993). Bio-accumulated pesticides and aquatic mutagens may reduce species' fitness, and water enrichment caused by agricultural run-off can precipitate changes in food abundance and, thus, disturb the ecological balance within a community. Pollution alone may not cause species to go extinct, but may catalyze a wide array of physical and chemical reactions that enhance genetic erosion. The combined impact of pollution and over-exploitation on age and size-class structure, may disrupt and destabilize aquatic ecosystems. To tackle the issue of pollution, fundamental human behaviour must be modified through education (Lackey 1994).

Research on polychaetes indicates that intense selection pressure associated with pollution can induce drastic phenotypic transformations and rapid population buildup of tolerant genotypes (Nevo 1990). Results indicate that the genetic cost associated with tolerance acquisition was very high. Due to their narrow genetic base, tolerant progenies were unable to adapt to the clean environment that emerged once the pollution sources were removed (Cognetti 1991 in Cognetti and Curini-Galletti 1993).

Climate Change

Global warming may have extensive impact on aquatic ecosystems. However, because of the uncertainty associated with global climate change and its projected magnitude of change, foresighted repercussions remain speculative (Larkin 1992). Some examples include the alteration of aquatic temperature regimes causing coral bleaching as well as coastal water levels affecting fish foraging and mating areas, fecundity, and egg and larval survival (Beatley 1991). Rising oceans may advance inland, causing increased salinization of freshwater systems.

Increased infiltration of ultraviolet (UV) light due to ozone thinning is another factor that has recently received greater attention, specifically with respect to UV as a causative agent of mutagenic effects on amphibian population at high elevations. Blaustein and Wake (1995) reported that UV light easily penetrates eggs found in shallow pools and damages the DNA resulting in population declines. Several scenarios may arise from climatic and atmospheric change and, in all likelihood, these will adversely affect aquatic biodiversity (Allan and Flecker 1993).

Aquatic Biodiversity Conservation Strategies

Targeting the Ecosystem

All of the above destructive patterns, either singly or in various combinations, accelerate environmental change and, in so doing, modify community composition, structure, and function by eliminating or reducing the abundance of those species not adapted to the altered environment. These disturbances however, may not necessarily reduce biodiversity *per se*. Some argue that disturbances generate biodiversity (Reice 1994). In fact, it is entirely possible that the new species assemblages may be more genetically diverse than their predecessors and perform the same ecological functions. Community composition, however, may be entirely modified and of little or no real or perceived economic value to humanity. To minimize the probability of valuable species bankruptcy, clear objectives for the conservation of biodiversity must be formulated.

Conservation policies must take into account that aquatic species are the only remaining non-domesticated agricultural resource of major significance (Ryman et al 1993). Accordingly, strategies aimed at conserving aquatic biodiversity should be similar to those used to conserve wild terrestrial species. Efforts to conserve terrestrial wildlife have primarily focused on ecosystem-level preservation, and so they should for aquatic wildlife. However, because aquatic environments are under intense pressure to provide food, pharmaceuticals, and industrial products to an ever-increasing human population, even greater diligence is required if aquatic communities, species, populations, and their habitat are to survive. To safeguard all levels of aquatic biodiversity, additional measures must be taken to control external stressors such as pollution, agricultural runoff, and deforestation and to ensure that sufficiently large aquatic areas are protected and more marine aquatic parks are developed. Marine protected areas can serve to protect species, habitats, and seasonal breeding grounds as well as promote the recolonization of adjacent degraded environments. Other uses include traditional fishing, recreation, and research.

In spite of its obvious advantages, the ecosystem-level approach may not afford taxonomic units on the brink of extinction the immediate conservation assurance necessary. Under such circumstances, efforts are needed to ensure that the organisms' genetic fabric is secured. Rapid implementation of *ex-situ* measures is particularly critical for species of traditional economic

importance. However, cryopreservation or other *ex-situ* techniques should not be limited to species of potential economic value alone because functional diversity may be compromised in the future. In less critical situations, *in-situ* community-management strategies that target multispecies assemblages are needed to complement gene-level conservation tactics.

Ex-situ measures preserve genetic resources outside of their natural habitat. Institutions conducting research on ex-situ conservation (either live specimens or cryopreserved) include zoos, aquaria, museums, universities, and private fish enthusiasts.

Where to Begin?

It is optimistic to think that all of Earth's inherent biodiversity can be conserved (Myers 1993). Soaring population pressure and increasing budgetary constraints heighten the conservation crisis. To effectively conserve aquatic resources, it is essential that we immediately focus on the *taxonomic hotspots* and highly productive environments susceptible to degradation: coastal, riverine, estuarine, coral reefs, and mangrove environments. Within these environments, the selection of which level of biodiversity to target and which approach to take will depend on the state of the fishery in general, or the species and their populations in particular.

Ecosystem health can be diagnosed in several ways. How reliably and consistently environmental health is measured depends on the range of parameters and the number of criteria considered. The index of biotic integrity (IBI) is a promising approach wherein fish are used as bio-indicators to evaluate and monitor aquatic health. The IBI is based on 12 fish population metrics ranging from species composition and richness to ecological factors (Rapport 1990, Karr 1981). The main drawbacks to using fish as bio-indicators include the selective nature and labour requirements for field sampling, and the impact of fish mobility on diel and seasonal time scales (Karr 1981). Other monitoring practices involve measuring or assessing primary productivity, phytoplankton composition, nutrient components, water column structure, and prevailing current

(Alexander 1993) Primary productivity is the photosynthetic capacity of cyanobacteria, diatoms, dinoflagelates, and other microscopic plant life. Because over 99% of marine productivity depends on phytoplankton (Thurman 1987 in Upton 1992), fluctuations in carbon fixation can serve as biological indices to measure and monitor ecosystem health over time and space (Alexander 1993). Problems associated with using microscopic plants as indicator species include taxonomic expertise is required, sampling, sorting, and identifying are difficult time-consuming tasks, life-history information for many of these species is limited, and results on obscure species are often of little relative value to the general public (Karr 1981). In addition, it is important to note that increased productivity may be an indicator of poor ecosystem health, as in eutrophic environments. Developing reliable early warning systems is critical for target and approach identification. The following two approaches have been identified as potential mechanisms for marine and freshwater management, respectively.

Large Marine Ecosystems (LME)

When coastal nations expanded their territorial waters to the 200-mile limit, they gained the legal jurisdiction and management responsibility for over 85% of the world's fishery resources (Keen 1983). One of the main objectives of the 1982 revision of the International Law of the Sea was to place a greater proportion of the world's most productive aquatic environments under the

Although oceans are estimated to cover 71% of the Earth's surface (Upton 1992), 90% of the open seas are either biological deserts or of low-productivity — the most productive and diverse areas (and consequently the most threatened) are estuaries, upwelling zones, and continental shelves (Avault 1994)

custodianship of coastal nations, and to evoke, within these coastal nations, a greater political willingness to sustainably manage these diverse ecosystems and the resources they contain. Secondly, because aquatic resources are often shared between nations, a regional approach to management was sought. International peer pressure was thought to provide additional moral incentive (Pearse 1992). The impact of territorial expansion on biodiversity, however, remains to be judged because of the commensurate increase in effort and capacity witnessed along with territorial expansion.

The Large Marine Ecosystems (LME) approach builds on the foundations of territorial expansion. Initiated in the early 1980s, the LME approach targets 49 unique marine and coastal environments (Figure 1) defined as "extensive areas of ocean space with distinct hydrography, topography, productivity, and trophically dependent populations" (Alexander

1993, Sherman and Alexander 1986 in Larkin 1993). A key feature of the LME approach is the designation of the functional ecosystem as the conservation unit. Consequently, the targeted species' entire physical habitat, along with the wide array of predators, prey, and parasites that directly affect the species' survival, are included (Norse 1993). The breadth of the LME approach facilitates realistic multispecies research and management. However, if such an approach is to succeed, neighbouring countries sharing an LME must collaborate. This regional dimension to coastal zone management should foster the development of strategies that seek to address issues such as transboundary pollution, introduced species, and foreign competition (Sherman 1989 in Alexander 1993). One major drawback to the LME approach is the production orientation taken to research and management. A much broader mandate is essential if issues such as biodiversity and ecosystems integrity are to be addressed.

In essence, the LME concept recognizes that "the sea consists of fairly distinct regions within which physical conditions, biological communities, fish stocks, etc. are so closely linked that they are best managed as a regional ecological unit" (Norse 1993)

Because of the complexity associated with, and the number of agencies responsible for marine production and conservation, management strategies have tended to be "fragmented, *ad hoc*, and reactive" (Norse 1993). The conventional sectoral approach to coastal zone management taken by many centralized bureaucracies has often led to piecemeal and sometimes counter-productive guidelines that reflect each agency's own agenda (Norse 1993).

A more proactive integrated management approach, wherein coastal and marine research and management policies are developed and coordinated in a coherent

Many international donors support the LME approach, including the Global Environment Facility, World Bank, UNDP, and FAO (Alexander 1993). Interested countries include Belgium, Cameroon, China, Côte d'Ivoire, Denmark, Estonia, Germany, Japan, Kenya, South Korea, the Netherlands, Nigeria, Norway, the Philippines, Poland, and Thailand (Alexander 1993)

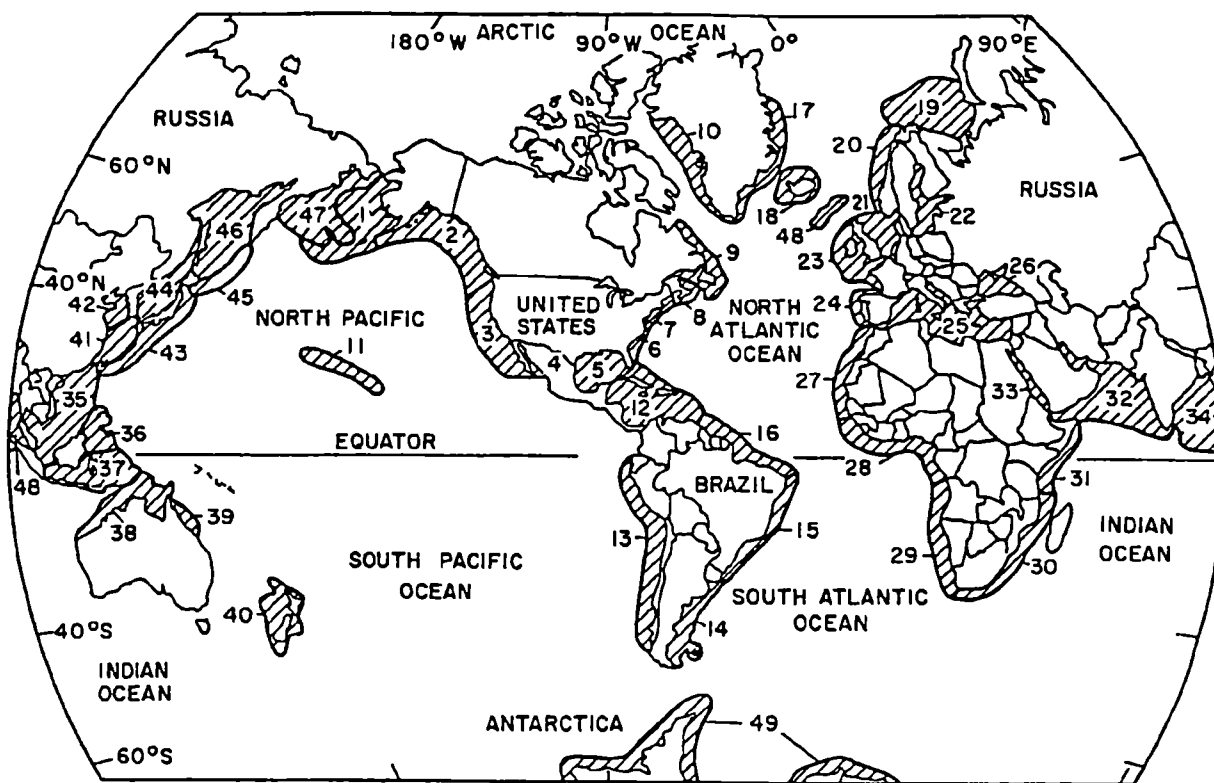


Figure 1 World map of Large Marine Ecosystems (Alexander 1993)

Key

- | | | |
|----------------------------------|---------------------------|------------------------------|
| 1 Eastern Bering Sea | 18 Iceland Shelf | 34 Bay of Bengal |
| 2 Gulf of Alaska | 19 Barents Sea | 35 South China Sea |
| 3 California Current | 20 Norwegian Shelf | 36 Sulu-Celebes Seas |
| 4 Gulf of California | 21 North Sea | 37 Indonesian Seas |
| 5 Gulf of Mexico | 22 Baltic Sea | 38 Northern Australian Shelf |
| 6 Southeast US Continental Shelf | 23 Celtic-Biscay Shelf | 39 Great Barrier Reef |
| 7 Northeast US Continental Shelf | 24 Iberian Coastal | 40 New Zealand Shelf |
| 8 Scotian Shelf | 25 Mediterranean Sea | 41 East China Sea |
| 9 Newfoundland Shelf | 26 Black Sea | 42 Yellow Sea |
| 10 West Greenland Shelf | 27 Canary Current | 43 Kuroshio Current |
| 11 Insular Pacific-Hawaiian | 28 Guinea Current | 44 Sea of Japan |
| 12 Caribbean Sea | 29 Benguela Current | 45 Oyashio Current |
| 13 Humboldt Current | 30 Agulhas Current | 46 Sea of Okhotsk |
| 14 Patagonian Shelf | 31 Somali Coastal Current | 47 West Bering Sea |
| 15 Brazil Current | 32 Arabian Sea | 48 Faroe Plateau |
| 16 Northeast Brazil Shelf | 33 Red Sea | 49 Antarctic |

fashion across sectors, would be more effective (Norse 1993) Cross-sectoral and inter-agency consensus building may often pose a formidable challenge However, strategies emerging from such a process may more accurately reflect the comprehensive scope of the activities that are necessary

The Five-Tier Approach for Freshwater Ecosystems

The impact of human activities on freshwater systems is significant From acid rain to water competition and habitat destruction, freshwater resources are under enormous stress Although the five-tier approach was developed for freshwater ecosystems in California, the principles are applicable to any stressed freshwater environment characterized with high endemism and rapid species loss (Moyle and Leidy 1992 in Moyle and Yoshiyama 1994) A key feature to this approach is the hierarchical designation of the watershed as the landscape conservation unit (Moyle and Yoshiyama 1994) Because watersheds may not encompass a species' entire range, this approach is judged as a medium-term solution, i e , less than 100 years (Moyle and Yoshiyama 1994)

The first tier involves an in-depth species inventory within the targeted area and the identification of those species deemed endangered, threatened, or rapidly declining Secondly, from the identified list, clusters of species known to routinely share restricted geographic ranges are formed By developing strategies for clusters of troubled species, the probability of preserving native habitat and local food chains is also increased (Moyle and Yoshiyama 1994) Because entire watersheds are often too large and locally unmanageable without adequate infrastructure and finance, and because of logistical problems associated with *official*

reserve and refugia status, the third step calls for the delineation of management units of *utilitarian* proportions (usually 50 km²) These first three measures aim to protect species and populations potentially on the brink of extinction They are

Each unit must have the following characteristics

- *large and diverse enough to accommodate the cluster requirements,*
- *headwaters and riparian zones must be protected,*
- *functional redundancy must be an implicit feature,*
- *unit replication is imperative, and*
- *within each cluster, population size must be large enough to avoid problems associated with small populations (Moyle and Yoshiyama 1994)*

only stop-gap measures, however, and will not ensure that ecosystems are permanently safeguarded. Consequently, the process is expanded in the fourth and fifth tiers where entire watersheds within a region and is followed by the integration of several key watersheds into a regional approach (Moyle and Yoshiyama 1994)

Priority Targets

Several criteria have been outlined to determine if a species' survival is in jeopardy. The four main factors considered by the National Marine Fisheries Service (NMFS) to establish a species' susceptibility include limited distribution, prolonged maturation period, rare due to limited ecological role, and excessive over-exploitation (Marine Fisheries Section and Endangered Species Committee 1991). Within highly productive marine and freshwater environments, initial conservation efforts should focus on those species assemblages most sensitive to perturbations and in immediate danger, e.g., species and populations with confined ranges, top level predators, and specialists.

Species with limited ranges are highly susceptible to habitat destruction and degradation and may be pushed to the brink of extinction by habitat alterations (Upton 1992). Paleontological studies of marine invertebrates indicate that widely distributed species are less vulnerable to extinction than range-restricted genera. Loss of higher taxa with limited ranges can only be measured over geological time scales. For example, coral-reef recovery rates are estimated between 5 and 10 million years (Sheehan 1985 in Jablonski 1991). Through the fossil record "evidence is accumulating that taxa and morphologies may have been lost not because they were poorly adapted but because they occurred in lineages lacking the environmental tolerances or geographic distribution necessary for survival" (Jablonski 1991).

A species or sub-species is considered endangered or threatened if it

- *is in danger of extinction,*
- *is ecologically extinct,*
- *is below 5% of its original adult population size, or*
- *is otherwise severely depleted throughout all or a significant portion of its range*
(Lagomarsino 1992 in Huntsman 1994)

Over-exploitation and habitat degradation are disrupting the predator-prey balance that characterizes many aquatic ecosystems (Alexander 1993). To what

extent such relationships are affected, and how the ecosystem responds to these changes, is a relative function of exploitation and habitat loss. Figure 2, a simplified version of the mackerel, herring, and sand lance stocks off the US northeast coast, illustrates the number of mammalian predators potentially affected by reduced prey abundance. Consequently, maintaining predator-prey balance to conserve marine populations requires sound ecological data and specific intervention measures. One strategy proposed to correct predator-prey imbalance is concentrating fishing effort on predators to allow prey populations to recover. However, the potential aftermath of such directional activities is not yet fully understood (Alexander 1993).

The innate genetic contrast between specialist and generalist species also has conservation ramifications for both marine and freshwater environments. Specialists, genetically programmed to seek out unique habitats with distinct niches, perform narrowly defined ecological functions. Typical generalists, on the other hand, are widely distributed over broad ranges of fluctuating environments in which they play numerous roles. Contrary to specialists, generalists tend to exhibit low genetic variability (Thorne-Miller and Catena 1991). In their study of marine teleosts, Smith and Fugio (1982) found a negative correlation between genetic variability and environmental range. Specialists from tropical, temperate pelagic, and intertidal/sublittoral habitats were highly variable genetically, whereas, generalists inhabiting demersal and polar environments were not. Concentrating on specialists initially, then, should be a conservation objective.

Single and Multispecies Management Strategies

Most fisheries management strategies to date have focused on individual species. These single-species oriented tactics, however, do not reflect the complex community nature that fisheries exhibit and consequently, many such efforts have not achieved anticipated results. Recently, emphasis has shifted to stock-management strategies that target multispecies assemblages and are sensitive to population dynamics (Murawski 1991, Cushing 1988 in Kenchington 1992). In addition, principles generated in landscape ecology are being incorporated to provide greater insight as to how

"Conventional management regimes have proven inadequate as they have frequently failed to protect fish stocks from depletion, and almost always failed to maintain prosperous fishing industries" (Pearse 1992)

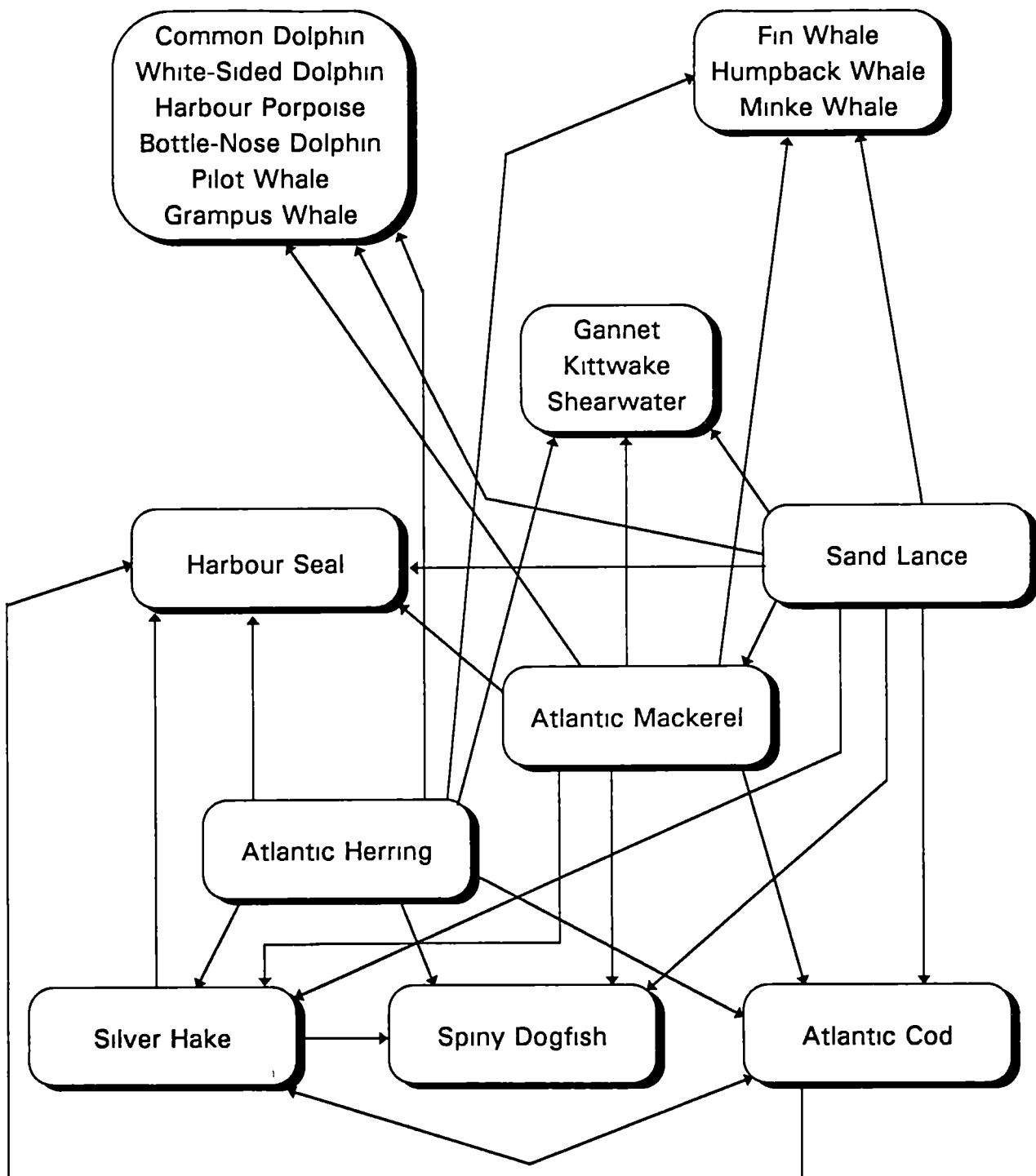


Figure 2 Predator-prey relationships among some fish, marine mammals, and seabirds of the pelagic ecosystem off the northeast US. For the sake of clarity, not all predator and prey species are portrayed. Arrows indicate the directions of biomass flow, and are based on feeding habits studies (Murawski 1991)

biogeographical parameters affect community interactions and ecological relationships such as predation and competition (Ray 1991) Research on multispecies assemblages will broaden our understanding of the *nuts and bolts* of fisheries, thus enabling scientists to more competently advise policymakers However, unless fishers themselves are integrated into the whole decision-making process, research will not have the desired impact on aquatic biodiversity conservation

Targeting the Gene

Immense gaps exist in our understanding of the ecology and reproductive behaviour of many potentially important native species In tropical aquatic ecosystems such as Lake Victoria, and the Amazon and Mekong watersheds, for example, many species are disappearing faster than they are being identified (Goldman 1994) This represents a significant loss of genetic biodiversity, the biological basis for evolution

It is upon this genetic biodiversity that aquaculture worldwide will increasingly depend as population pressure continues to mount Because most aquaculture broodstock resources are wild, *in-situ* conservation of these wild gene pools and their ecological support systems will remain vitally important *Ex-situ* conservation of these genetic resources, however, is an additional precautionary measure that must not be overlooked

***Ex-Situ* Conservation of Aquatic Resources**

At the gene level, two approaches to conservation are taken live *ex-situ* efforts includes zoos, aquaria, and museums where captive breeding and propagation are routine procedures The suspended *ex-situ* strategy consists of gene banks, where semen is cryopreserved for future access (Soulé 1991) Advantages to the *ex-situ* approach include safeguarding species on the brink of extinction, long-term storage and breeder access to indigenous germplasm, ease and immediacy of techniques, and low maintenance costs The representative nature and narrow genetic base of collected samples, the capacity to maintain viable populations, the lack of facilities and habitat generated selection pressure, and the need for long-term favourable policies and continued funding are drawbacks that currently limit the scope of *ex-situ* conservation In addition, the traditional knowledge on how, when, and where the conserved germplasm is to be used is frequently lost (Wood 1993)

As reservoirs of genetic resources, gene banks are also sources of unique and disease-resistant strains for future introduction into established aquaculture or captive breeding programs. A major benefit of *ex-situ* conservation is that cryopreserved genetic resources may serve in evolutionary, reproductive, and developmental biology research. In addition, such material may be used to advance spawning coordination and to overcome constraints associated with the movement of fresh sperm (Harvey 1990). In areas where transport of live fish is risky or expensive, cryopreservation techniques are very useful in the re-establishment of populations and in the rapid introduction of genetic material into dispersed, inbred populations. To date, *ex-situ* efforts have focused primarily on commercially important freshwater species and on preservation of endangered genetic material.

In an effort to protect endangered fish populations, lakeside aquaculture and captive breeding are often utilized. The aim is to buy time to evaluate options and to design regional conservation approaches (Warmolts 1994).

However, the impact of increased genetic drift and inbreeding in many hatchery-based enhancement strategies has led to serious questions concerning population viability (Bartley 1994). *Ex-situ* techniques can allow for the rapid introgression of new genes into bottlenecked breeding programs, thus helping to improve survivorship of released progeny into restored or altered habitats.

In Lake Victoria, international conservation efforts are concentrating on the haplochromines, tilapias, and other traditional food species, e.g., Oreochromis esculentus and Labeo victorinus.

Genetic–Environment Interactions in Fish Breeding

Many current fish breeding programs, modelled after conventional animal-improvement strategies, reduce genetic diversity by selecting only a few desirable traits for seemingly homogenous culture environments (Doyle et al 1991). Doyle et al (1991) suggest that genetic variability may be promoted through selective

Many modern salmonid breeding programs emphasize adaptation to intensive management and disease resistance, and ignore genetic–environment interactions in an effort to produce all-purpose breeds that yield well across a variety of environments.

diversification, a breeding regime wherein the preservation of strong genetic-environment (GE) interactions (variation of the relative performance of phenotypes among different culture environments) are recognized as a key component of breed development. They point out that intense selection pressure between and within breeds will conserve diversity, not primitiveness. Because a wide range of culture environments and behavioral adaptations exist for many aquaculture species, varying selection pressure on desired traits or behaviours specific to that culture system will influence GE interactions and breed creation.

A strong GE effect can occur when a wild breed is selected across two or more different environments (Doyle et al 1991). The genetic conservation component arises from stable fitness variations (polymorphisms) that create strong GE effects and allow species to adapt to heterogenous environments

Examples of GE moderating factors include management intensity, feed types and schedules, stocking size and density, water and soil quality, foraging, and predator exclusion (Tave 1994, Doyle et al 1991)

(Tave 1994). Breeds developed from such a strategy may serve as a living library to accommodate changes in consumer preferences, economics, husbandry techniques, and national or regional genetic improvement strategies. Such a breeding strategy is a compromise between the need for increased yield and for genetic biodiversity conservation. The Genetic Improvement in Farmed Tilapias (GIFT) project in the Philippines is investigating GE effects across a wide range of culture environments including ponds, cages, and ricefields. The GIFT project is the first holistic fish breeding project in the tropics to include conservation and prudent use of aquatic genetic diversity. Such an endeavor is extremely important for tropical developing countries with diverse aquatic environments, many of which are often under heavy pressure to produce food.

Molecular Biology in Aquatic Biodiversity Conservation

To effectively address the issue of aquatic biodiversity conservation, it is imperative that we overcome our inability to pinpoint genetic dissimilarities among and between individuals, populations, species, and stocks, and to monitor their fluctuations over time and space. With the advent of molecular tools for biological research, significant progress in fisheries management and conservation is expected. However, techniques such as morphometric analyses and protein electrophoresis may lead to erroneous conclusions or do not detect sufficient levels of variability to answer finer point questions (Larkin 1992).

Morphological traits often show weak genetic correlation due to strong environmental influences, and protein isozymes are sometimes invariable over large sample sizes (Utter and Seeb 1990). In the early 1980s, the development of restriction fragment length polymorphism and polymerase chain reaction methodologies made identification of differences in sequence and form of DNA nucleotides possible. These tools are now enabling geneticists to distinguish among and between these different levels of biodiversity.

Fisheries and aquaculture geneticists are using many highly pervasive technologies to answer questions pertaining to fish and shellfish population genetics and evolutionary lineages. The numbers of DNA sequences available for discrimination studies at the species level are many orders of magnitude larger than those features described for morphometrics (Hubbs and Lagler 1947 in Wirgin and Waldman 1994) and electrophoresis (Murphy et al 1990 in Wirgin and Waldman 1994). DNA polymorphisms can provide a wealth of variation in the description or induction of useful markers for identification by preferential breeding of genetically distinguishable individuals (Castelli et al 1990). Genetic markers are also heritable, thus facilitating multi-generational research (Wirgin and Waldman 1994). Using mini- or micro-satellites in high resolution analyses such as DNA

*Application of DNA analyses
Wirgin and Waldman (1994)
summarize the potential applications
of molecular techniques to fisheries
problems*

- *stock identification within mixed stock assemblages,*
- *relative population contributions to stock productivity and mixed stock analysis,*
- *quantification of genetic variability and inter/intrapopulation change,*
- *maximization and maintenance of genetic diversity and integrity in hatcheries,*
- *discrimination of hatchery versus wild fish,*
- *identification of hybrids and gene flow introgression analyses,*
- *performance evaluations through genetic marking,*
- *gender identification in non-breeding seasons,*
- *forensic analysis,*
- *restoration of extinct populations via genetic matching,*
- *taxonomic investigations to protect endangered fishes, and*
- *biomarkers of contamination exposure (xenobiotically sensitive genes)*

fingerprinting, even genetic differences at the individual level may be detected. The choice of technique depends on the amount of resolution the problem requires. Many stocks or populations, such as the Atlantic herring (*Clupea harengus*), exhibit low levels of genetic divergence over wide pelagic zones, and thus require high resolution techniques (Smith et al 1990). On the other hand, because salmonid stocks are *isolated* and exhibit high levels of genetic divergence, genetic differences may be detected by protein electrophoresis. The major hindrances to working with DNA polymorphisms are that DNA extraction and preparation are labour intensive and require numerous fresh samples to establish the data sets required for result validation. Because replication is essential in this procedure, resolution may be sacrificed for speed. If no significant statistical differences are found after a reasonable search effort, molecular techniques allow for increased survey of alternate sections of the genome to find useable markers (Waldman et al 1988).

The Conservation Unit

Ecological diversity can give rise to specific local adaptations and thus, important genetic diversity. One of the major stumbling blocks to conservation is delineating the unit of conservation. The US endangered species act focuses on "any distinct population segment of any species of vertebrate fish or wildlife which interbreeds when mature." In terms of conservation, however, there are serious questions concerning the use of the species complex as a unit. An alternative that is gaining greater attention is the evolutionary significant unit (ESU). Waples (1991) defines an ESU as a reproductively isolated population that has undeniably contributed to the species' evolution. In determining effective reproductive isolation, evolutionary contribution, and population distinctness, special consideration must be given to the following features: anadromy/nonanadromy, run time, effect of artificial propagation programs, historic and present effective population sizes, and mixed stocks or population clusters (Waples 1991). Those populations occupying unique habitats and exhibiting special ecological adaptations can also be considered ESUs (Waples 1991).

Various genetic analyses will be used to address problems relating to ESU assigning. With statistical data analysis and interpretation, comes the concerns that statistical significance does not imply evolutionary significance, and that genetic differences do not suggest genetic distinctness (Waples and Teel 1990). An evolutionary component must be considered (Utter 1981). Smith et al (1990) point out that even though many marine stocks may occur as large regional clusters, consisting of numerous spatially unique spawning groups with very little

discreet taxonomic status, their overall evolutionary contribution to the species should not be underestimated. Life-history research into migratory habits, home-range patterns, seasonality of behaviours, use of foraging and spawning areas, and biological responses to habitat alteration, must be included within ESU conservation programs (Reid 1993)

Because of the alarming rate at which we are altering aquatic ecosystems, *ex-situ* techniques are vital if gene pools are to be conserved. Due to our lack of empirical knowledge, more extensive research into determining ESUs and understanding genetic stock structures is needed.

Conservation emphasis must be placed on the application of efficient and cost-effective techniques relating to the conservation of ESUs. How and where the lines are drawn in the process of saving the maximum amount of effective biodiversity in aquatic ecosystems must be determined. What are our priorities in the face of ever-decreasing resources? In aquaculture, *ex-situ* technologies must be developed in conjunction with husbandry improvements, environmental impact awareness, and ecological technologies to create sustainable production systems. *Ex-situ* strategies, however, should never be seen as an alternative to maintenance of aquatic ecosystem integrity. A balance must be struck between conservation ethic and utilitarian concern. Target criteria such as ecosystem function (keystone species, top level predator-prey interactions, evolutionary lineage), commercial importance, and traditional value must be defined. Genetic analyses and *ex-situ* techniques must be incorporated into a conservation framework based on adaptive co-management strategies, recognition of pertinent indigenous knowledge, and effective government policies.

"The identification of ESUs within species was recognized as a difficult task, requiring the use of natural history information, morphometrics, range and distribution data, as well as protein electrophoresis, cytogenic analyses, and restriction mapping of mitochondrial and nuclear DNA"
(Ryder 1986)

Cryopreserved material represents a genetic snap shot of local populations at a specific time in evolution, and may help breeders to deal with both present and future crises

Biodiversity Conservation and Management

The question of aquatic biodiversity conservation literally rests with resource management. If stocks were sustainably managed and habitats preserved, conservation would likely not be as grave an issue — the crisis response. Although stock-management strategies worldwide vary almost as much as do cultures, two contrasting models emerge, open access (common property) and traditional. It is not the purpose here to expound in any great detail on the advantages and disadvantages of each, but rather to simply highlight some of the main drawbacks to each approach under present-day conditions, and to propose how greater strides in aquatic biodiversity conservation may be achieved.

Open Access Regimes

Open access regimes are based on the fundamental principle of common property under which no one individual can control the resource (Hviding and Jul-Larsen 1993). In most proponent countries, open access is backstopped by rules and regulations set and enforced usually by a central authority. Ruddle (1988) contends that "marine fisheries in Western societies are perhaps the last major resource to have been exploited under open access regimes." The very absence of custodianship signals the need for alternative marine conservation and management (Upton 1992).

Society, in general, benefits under a common property regime as long as the sought after resource remains plentiful and its exploitation remains economically viable. As pressure on the fishery mounts and stocks become depleted, however, fishers inevitably end up competing against one another for the same fish, ultimately leading to over-capitalization on gear as individuals aspire to increase their share of the resource (Pinkerton 1989). Keen (1983) maintains that "excess effort has come to be recognized as the major and most intractable problem in marine fishery resources management." The root of the problem according to Keen (1983) rests with four incentives fishers face regarding both resource exploitation and enhancement.

These issues have long exasperated fisheries authorities in their quest to sustainably manage aquatic resources under open access on a national scale. The overwhelming complexities witnessed during efforts to conserve whales, anadromous salmonids, and pelagic herrings (Ryman et al 1993) are testimony to the problems associated with open access on an international scale.

Within countries adhering to common property principles, attempts to curb fisheries over-exploitation have ranged from limited entry to numerous restrictions on gear, species, and season. Regrettably, these efforts have not often succeeded because they inadequately address the problems inherent to common property regimes (Norse 1993). In an effort to further reduce accessibility to common resources, quota allocation has also been proposed.

Individual transferable quotas (ITQs) are a form of exclusive right to either a fixed or fluctuating portion of a fishery (Pearse 1992) and once awarded, fishers are free to determine how and when their allotted share of the total allowable catch is to be harvested (Norse 1993). Although ITQs are legal assets that can be bought and sold, they are not considered private property (Norse 1993). Because there is a tendency to under-report and to high-grade, i.e., dump less valuable landings out at sea, quotas require extensive policing and consequently, are costly to implement and

The four main incentives are

- *the incentive to take the best first,*
- *the incentive to continue exploitation as long as the user's opportunity costs are met although the resource is greatly reduced in productivity,*
- *the incentive to continue to increase investment in exploitation even after the maximum sustainable yield is exceeded if demand forces the value of the resource upward, and*
- *a lack of incentive to invest in the productivity of the resource although to do so would, in terms of total productivity, provide a handsome return on investment (Keen 1983)*

The concept of ITQs, initiated in New Zealand, has also been implemented in Australia's southern bluefin tuna fishery, Canada's Pacific halibut fishery, and in the US Atlantic wreckfish, ocean quahog clam, and surf clam fisheries (Norse 1993)

administer (Keen 1983) If implemented on a wide scale, ITQs could eventually lead to the transfer of management responsibilities to those with the greatest stake in the fishery, the end-users. In fact, some predict that ITQs (or a reasonable facsimile) may result in fisheries privatization and the abandonment of the long held view that open seas are common property (Scott 1989 in Pearse 1992)

The conceptual basis to ITQs, however, is indelibly ingrained in conventional management and quantitative theory that assumes that "control of fishing mortality can lead to an increase in a species numerical abundance" (Wilson et al 1994) Substantially greater research and funding are required to confirm this because some argue that "the complexity [and potential chaotic nature] of aquatic ecosystems precludes predictability of the sort required to exercise the numerical control envisioned by current theory" (Hilborn et al 1993 in Wilson et al 1994) Enlightened proponents submit that although "chaotic systems are deterministic with clear cause and effect relationships the variety and non-linearity of the relationships make system outcomes almost impossible to predict" on a long-term basis (Wilson et al 1994) They emphasize that if management targeted "HOW fish were caught rather than HOW MANY," better results might be obtained (Wilson et al 1994) This very brief outline of the western scientific approach to management illustrates only a few of the very perplexing issues facing authorities and managers caught in the common property paradigm

A qualitative, parametric approach to fisheries management based on such " life stage governing factors as habitat, migration, spawning, growth, predation and other attributes " may improve the current 30-50% forecasting accuracy (Wilson et al 1994)

Traditional Management Systems

In many regions of the world, aquatic resources are traditionally managed under a community-based form of sea tenure, wherein access to coastal and inland waters is determined by society (Hviding and Jul-Larsen 1993) The proprietary nature associated with sea tenurial

User rights are defined as "a claim, consciously protected by customary law and practice, to a resource and/or the services or benefits that derive from it" (Ruddle 1994)

systems varies from access entitlement to the complex legal system of Japan (Ruddle 1988) Sea tenure systems may be defined as the "ways in which fishermen perceive, define, delimit, *own*, and defend their rights to inshore fishing grounds" (Emmerson 1980, Acheson 1981, Ruddle and Akimichi 1984 in Ruddle 1988) Within a sea-tenure framework, user rights to specific regions, species, gear, or seasons are allocated to individuals, families, or clans usually by an elder or community leader (Ruddle 1988) Granting of user rights may be by virtue of birth, marriage, or cultural status within the community (Doulman 1993) Because user rights only confer the privilege to use the resource and not own it, these rights are generally not transferable (Doulman 1993)

In many of the cultures where traditional management systems prevail, an intimate bond with resources exists, and coastal and shallow inland waters are considered an extension of the community land base Consequently, many sea tenure systems are founded on the social organization and cultural dimensions of the community (Ruddle 1988) Upon bestowal of user rights, recipients are committed to, and must abide by, often unwritten and informal management and conservation guidelines established and enforced by the community (Ruddle 1994) Many traditional measures such as selective harvesting and strict control strategies for vulnerable species are based on sound ecological principles and have successfully minimized over-exploitation (Doulman 1993) Many traditional conservation strategies were designed under low population pressure, however As population density increased, measures increasingly became more sophisticated (Doulman 1993) Intense population pressure can (and in many cases has) exceed the potential conservation limits traditional measures were designed to achieve In addition to population, social change and the advent of commercial fishing opportunities with modern gear are causing many of the traditional conservation structures and management approaches to breakdown, ultimately resulting in stock depletion and habitat degradation, e g , Gulf of Thailand, the Philippines, Indonesia, and the South Pacific (Doulman 1993)

Based on this short discussion of contrasting strategies, three fundamental issues emerge the issue of property rights, the lack of synergy between authorities and fishers, and the breakdown of traditional management systems Although headway with respect to property rights is being made via territorial expansion (Exclusive Economic Zones) and potentially with ITQs, serious questions regarding allocation, regulation, and compliance remain unanswered Although governments and fishers disagree on many issues, collaborative efforts to resolve the conflicts are being made It is now widely recognized that local knowledge and data sharing may significantly improve stock assessment such that generated analyses will be more comprehensive, accurately reflect biosocioeconomic

realities, and dispel much of the skepticism fishers feel for many legislated policies. In addition, community willingness to participate in resource enhancement, decision making, and monitoring is increasing and encouraged. The concept of shared partnership is emerging, albeit slowly. In as much as traditional systems are concerned, here lies a veritable opportunity to acquire a greater understanding of truly time-tested management models and mechanisms that may be incorporated into modern management schemes. Because many traditional systems have already been hybridized with market-based models (Ruddle 1988), this may be an opportunity to ascertain how best a blend of both may be achieved.

Greater endorsement of community-based approaches is beginning to surface as the option of co-management gains legitimacy (Pinkerton 1989) and as fiscal restraints grow more severe. "This shift comes at a time of global economic change which has shown the limited ability of governments to buffer communities against change" (Pinkerton 1989). As with traditional management systems, the option of co-management "work best in fisheries where the number of parties involved is small, where they are similar in size and have similar interests, where there is a tradition of cooperation, where the organization [or community] regulates its members' activities, and where it has unquestionable authority" (Jentoft 1989 in Pearse 1992).

Because aquatic ecosystems have multiple uses, management objectives must aim to minimize use conflicts, maintain ecosystem health, increase scientific understanding, and sustainably generate wealth (Alexander 1993). These objectives must be defined by consensus between fishers, local communities, researchers, and government officials. To effectively meet these objectives, co-management strategies must be implemented within a legally binding framework, thus ensuring that rights over resource use and conservation are protected. The Biodiversity Convention and Agenda 21 affords nations the legal basis upon which to build comprehensive conservation strategies. The challenge is now ours.

Recommendations

Strategies to conserve aquatic natural resources will be formulated under the auspices of the Biodiversity Convention and Agenda 21 and the UN Convention on the Law of the Sea. These strategies must promote the rational and sustainable use of endemic and highly productive marine and freshwater ecosystems. Research on *in-situ* conservation, backstopped by *ex-situ* preservation and long-term monitoring commitments, are required. These approaches will foster a greater understanding of the relationship between environmental factors and human resource use patterns.

The following is a list of recommendations that, if implemented, may help to ensure that aquatic biodiversity are conserved. In an effort to gain a greater understanding of the ecological complexities associated with *in-* and *ex-situ* conservation of aquatic biodiversity, potential research issues are also suggested. These recommendations are, in part, a summary of those outlined in the Expert Consultation on Utilization and Conservation of Aquatic Genetic Resources (FAO 1993). Aquatic habitat destruction and degradation are recognized as primary threats to biodiversity, and consequently, it is crucial that appropriate measures be taken to reduce continued habitat loss. The challenge of modifying, and if necessary, suspending or abolishing destructive harvesting practices such as trawling, or the use of explosives and toxic chemicals, must be met. It is also imperative that policies that inadvertently create the incentive for fishers to high-grade, i.e., dump less valuable catches out at sea, be eliminated. Furthermore, management strategies and gear technologies must be developed to significantly reduce bycatches, particularly those associated with shrimp trawling and the use of drift nets.

In an effort to achieve these conservation objectives, an international advisory committee, linked directly to the donor and banking communities, could be commissioned to oversee project proposals and loan applications. Approval granting could be made conditional on the applicant nation's willingness, capacity, and track record to abide by, and enforce a set of provisions and standard code of practices pertaining specifically to biodiversity conservation. This kind of leverage may motivate nations to take the necessary steps to ensure that aquatic biodiversity is effectively conserved. For those nations where

adherence poses too formidable a challenge, either due to lack of technological expertise or adequate facilities, additional funding should be made available to ensure that compliance is observed and the obstacles overcome. Such a process must not, in any way, be an impediment to development, but rather, an analogous measure to environmental impact assessments, now routinely conducted prior to project approval.

In-situ conservation of aquatic ecosystem integrity must encompass the protection of species assemblages and their functional inter-relationships. If the LME and five-tier approaches are acknowledged as appropriate initiatives to achieve these objectives, then specific measures must be taken to ensure that the political willingness to collaborate in the sustainable management of these designated zones is fostered between those nations sharing either an LME or a watershed. Because of the complexities associated with regional collaboration, non-partisan international bodies, such as those within the CG system and FAO, could negotiate agreements to seek appropriate solutions and sound management strategies amenable to all parties.

In terms of required research, several topics emerge: the impact of continued harvesting on population dynamics and demographics, the ecological role of lesser known taxonomic units, the functional redundancy – population resilience phenomenon, endangered marine species status re-definition, greater emphasis on selective diversification in breeding strategies, and increased evidence and support for the ESU concept as the conservation unit. Recent findings indicate that detrimental changes in life history traits, and shifts in natural population demographics brought about by continued over-fishing, may be reversed by reduced harvesting intensity (Altukhov 1993). Increased research is needed to decipher what the mechanisms associated with selection pressure and continued exploitation are, and potentially, how regional, national, and community-level action plans can be formulated to ease harvest pressure to sustainable levels and thus allow taxonomic units of ecological and economic importance, now at critically low levels, to recover.

With current bycatch rates estimated at approximately 30% (Alverson et al 1994), populations levels of lesser known taxons may be significantly altered, which in turn, may adversely affect their ability to adequately carry out their ecological functions and thus destabilizing entire ecosystems. An in-depth understanding of their ecological role and of the consequences of continued exploitation is absolutely essential if sound measures are ever to be taken to ensure ecosystem stability.

The functional redundancy – population resilience phenomenon has not received sufficient research attention. In certain marine ecosystems for example, functional diversity and redundancy may not be as pronounced as in terrestrial systems either due to fewer species within each aquatic trophic level, more trophic levels, or a greater number of species performing identical or similar functions in terrestrial systems (May 1988). If redundancy is in fact less in aquatic systems, then these ecosystems may be less resilient than their terrestrial counterparts, and consequently, unable to sustain similar exploitation levels. Understanding the principles behind the redundancy phenomenon will provide us with greater insight into population composition, structure, and the ecological function that different levels of biodiversity perform.

Greater research is also needed to re-evaluate criteria presently used to judge if marine species should be listed as endangered, threatened, or overfished. Huntsman (1994) submits that these categorical definitions clearly need re-defining, as in their current state, they are ambiguous and *subject to considerable debate*. In this regard, Myers (1993) cautions against conservation procrastination for the sake of *inconclusive evidence* because by the time absolute data are collected and compiled, it may in many cases be too late to make any decision at all. Under the American system, although legal ramifications associated with listing of endangered species (or populations) are designed to help depleted stocks recover, conservation efforts in the last 10 years have not culminated in even one species being removed from the endangered list (Williams et al. 1989). It was noted, however, that had efforts not been made, the list of 139 additional endangered species would have been much greater (Williams et al. 1989). The fact that despite considerable effort, no species was removed from the endangered list may be interpreted as a warning signal indicating that effective conservation strategies are lacking. Adequate measures are needed to ensure that the health of the fisheries and the fishers is maintained.

If genetic diversity within cultured breeds is to be maintained and enhanced, selective diversification will have to be incorporated into breeding strategies and programs. Concerted efforts must be made to encourage breeding at the local level over a wide range of culture environments. Decentralization of breeding strategies is absolutely necessary if farmer economic decision-making is to be used as a criterion in breed development. Increased research to develop evaluation tools that critically assess how well breeding programs maintain and promote genetic diversity is needed.

A greater understanding of the mechanisms by which ESUs are formulated is required if science is to clearly define ESUs. Research should focus on

developing user-friendly DNA analytical tools such that ESUs are more readily identified

Ex-situ conservation strategies complement *in-situ* efforts by providing supplementary protection for those species deemed important or in critical need of protection, and whose reproductive biology will allow for propagation. National aquatic research policies must be formulated to determine the most suitable combination of *in-* and *ex-situ* conservation strategies. International support and collaboration should assist national programs in developing fish taxon advisory groups as well as conservation and breeding programs. Future directives must focus on molecular technique simplification and cost reduction, such that specific applications are transferable to developing country realities.

For enhancement and restocking programs, attention must be placed on proper hatchery techniques to minimize genetically disruptive selection pressures, thus ensuring better offspring survival. Responsible hatchery procedures must accompany any *ex-situ* program that releases fish into the wild (Bartley 1994). In addition, it is highly recommended that genetic characterization of recipient and source stocks be conducted and that stocking material be genetically marked, particularly where exotic species are being introduced or where native populations are being enhanced with hatchery-reared stocks. It is further recommended that adequate measures be taken to ensure genetic differentiation among populations by restricting gene flow patterns in an effort to minimize hybridization, introgression, and inbreeding (FAO 1993). Developing breeding strategies along the lines of GIFT, which promotes genetic diversity, should be initiated with other taxa in different regions. *Ex-situ* conservation strategies must be considered within the broader context of genetic resource ownership and access, equitable distribution of benefits derived from gene use, and the cost-benefit ratio of cryopreservation technology.

Linkage of gene banking initiatives into a global network, e.g., with the CG system or the International Network on Genetics in Aquaculture (INGA) as well as regional systems such as Aquaculture Genetics Network in Asia (AGNA) will provide increased focus on the importance of aquatic genetic resources and help to better define and coordinate international research, conservation, and aquaculture development. These linkages should take into account national aquatic biological surveys with emphasis on those species most important to national fisheries, aquaculture programs, and sensitive ecologies. A global database on aquatic resources such as ICLARM's FISHBASE and JBL Smith's (South Africa) FISHLIT would assist in augmenting the Species Inventory System of databases. *Ex-situ* genetic studbook management for fish and other

aquatic organisms can be developed with colony management computer programs such as CERIC (Reid 1993) The conservation and sustainable management agendas of organizations such as the Aquatic Conservation Network, the Sustainable Fisheries Network (Canada), the Pan African Association of Zoological Gardens, Aquariums and Botanic Gardens, and the IUCN Captive Breeding group should be coordinated and promoted Collaboration with UNESCO's Coastal Marine |

Some gene banking programs include the International Fisheries Gene Bank (IFGB) (Canada), the Nordic countries (salmonids), USA (Dexter National Fish Hatchery - endangered fishes of the American Southwest), Hungary (land races of European carps), China (Chinese carps), Philippines (Tilapias), Venezuela (planned for Colossoma), and the Netherlands, USA, UK, and Kenya (endangered Lake Victoria species)

(COMAR) program, which stresses "a definitive contribution to the International Research Programme on Marine Biodiversity and the application of preventative and corrective measures to the loss of biodiversity and to the imbalance between living and non-living systems due to anthropogenic or natural episodic and catastrophic events" should be encouraged and strengthened at all political levels

A diverse cross-sectoral representation of individuals concerned with the global health of fisheries and aquatic ecosystems must be mobilized to increase the overall awareness of challenges facing the *in-situ* and *ex-situ* conservation of our aquatic resources

The cornerstone to biodiversity conservation is inter-generational equity, the assurance that future generations gain equal access to essential biological resources Tomorrow's genetic library is dangerously eroding (Myers 1993), therefore, there is a new urgency to conserve the planet's genetic endowment In addition to numerous treaties, conventions, and protocols, the international community has recognized this urgency by stiffening environmental legislation and policy with the endorsement of the *precautionary principle*

Cameron and Abouchar (1991) define the precautionary principle as "a guiding principle which ensures that even if no conclusive scientific proof linking a given substance or activity to environmental damage exists, that the potential threat of that substance or activity to the environment be sufficient grounds to prevent either from adversely affecting the environment " Interpretations of the precautionary principle range from acknowledging environmentally detrimental

activities and taking corrective measures, to ordering "polluters to establish by some appropriate burden of proof that their activities are not releasing potentially eco-reactive substances into the environment and thereby causing damage" (Cameron and Abouchar 1991) In other words, the onus to demonstrate that an activity is environmentally benign must lie with those responsible for the activity, rather than with the public to prove otherwise In many cases, scientific evidence is not necessary to determine if human activity is adversely affecting the environment, but only to assess the extent of the damage incurred (Myers 1993)

The precautionary principle has been incorporated into the legal framework of several international agreements and protocols endorsed by nations worldwide (Cameron and Abouchar 1991) The Bergen Declaration commits its signatories to "anticipate, prevent and attack where the threat of serious or irreversible damage exists and that, a lack of full scientific certainty is not sufficient cause for postponing the implementation of cost-effective measures to prevent environmental degradation" (Bergen Declaration taken from Cameron and Abouchar 1991)

Cooperation between end-users, local communities, researchers, government officials, and managers is necessary if the broad spectrum of potential systems, conservation options, and impacts are to be challenged Proposed ecosystem interactive strategies must encompass traditional knowledge and social value systems Community participation in project development and implementation is crucial and local values and perceptions must be incorporated to improve quality of life

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