TROPICAL MARINE BIODIVERSITY OF THE WORLD: A TREASURE WORTH PRESERVING

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Summary

As scientists, administrators, and concerned people move towards the next Earth Summit in 2002, we must aim to achieve significant changes in the way tropical marine

resources are used and abused. We need to use education to help governments all over the world see the connection between sustainable development and knowledge about species and ecosystems. The knowledge that is presented in this summary of life support systems needs to be used to make it impossible for corporations and governments to ignore unsavory environmental issues. No less than the fate of the tropical seas is at risk and to save them for ourselves, our children, and the people who use them, we need to address the issues discussed here. We need compelling, strong evidence, detailed plans for action, and focus; without significant changes in the way humans use the tropical seas, the problems and issues discussed in this essay will escalate and grow.

1. Introduction

Tropical marine biodiversity commands a universal fascination. It attracts on television, in magazines, in foyers of hotels and airports. Colorful fish and weird creatures symbolize the mysterious, the exotic, the dangerous and the unknown. The diversity of the tropical oceans is second only to the tropical rainforest in terms of species, yet, because we are land animals, we have seen and understood much less of the underwater world. Human activities threaten the survival of species and resources and are changing the structure and functions of marine ecosystems in ways we do not understand. Man-made stress on ocean systems is global but reaches maximum damage in the areas with maximum biodiversity, the two ecotones or interfaces between the ocean and its surroundings. These are the sea surface or sea/air interface where ships travel, pollutants are concentrated and maximum marine production occurs. The other interface is the seabed or benthos, where fish feed, plants grow and sewage is deposited.

The area of the world oceans where the sea, the air and the land meet is most biodiverse of all. The land/sea/air interface or coastal zone is where the natural forces of sunshine, waves and tides, interact with the millions of people who are attempting to coexist with coral reefs, seagrass beds, mangrove swamps and the economic forces of exchange rates, GNP and export markets. If land price is an indicator of human value, a view of the land/sea/air interface; the beach, cliffs or harbor, has the highest possible value, yet suffers from the most conflicts, compromises and stresses. Many of the largest cities in the tropics are coastal and the oceans surrounding them are functionally dead. The undersea ecosystems of Jakarta, Hong Kong, Manila have changed from diverse, colourful, exotic wonderlands to stagnant, stinking, toxic piles of refuse.

This gloomy picture doesn’t have to be so, sufficient knowledge exists to stop or reverse biodiversity loss in the tropical ocean. It is possible for the human/ocean interface to be sustained without loss of the other functions provided by the tropical oceans. It is clear that fishing reduces biodiversity and has profound effects on populations and ecosystems. All fisheries of the world are overfished with too many fishers catching too many fish. Many fisheries are even subsidized by the tax payer so in effect fishers are paid to reduce the biodiversity of the sea and so continue to undermine the ecosystems which sustain their livelihood. Marine food webs in fished areas have changed from long lived, high trophic level fish such as groupers and snappers to short lived pelagic fish such as jacks and mackerel scads and/or invertebrates especially octopus and squid.

Chemical pollution and eutrophication are important because although the sea seems endless, with a large potential for dilution, it must be understood that the oceans are always downstream from land-based pollution. Whatever pollution affects the land or rivers; toxic chemicals, oil, or agricultural pesticides, all eventually end up in the sea. Other factors which reduce biodiversity in the sea are physical alterations to coastal habitat; invasions of exotic species; and global climate change, including increased ultraviolet radiation as well as global warming with its effects on ocean circulation and hence nutrient supply. These stresses continue to affect all aspects of marine life from the intertidal zone to the deep sea and have resulted in clear, serious, and widespread social, economic, and biological impacts including:

- Dramatic reductions in the populations of almost every edible fish and shellfish species;
- Extensive changes in species composition and abundance of the communities of important plants and animals in the damaged ecosystems;
- Changes in the basic functioning of ecosystems including the sources of primary production, the trophic pathways and energy flow, and biogeochemical cycling;
- Reduced aesthetic and recreational value of many coastal habitats, such as coral reefs, estuaries, rocky shores, and beaches; and
- Reduction or extinction of species with important potential bioactive compounds.

To evaluate the scale and consequences of changes in the ocean's biodiversity due to human activities and recommend strategies to correct these problems will require a concerted proactive approach by many people. Unfortunately there are gaping holes in what we know and understand about marine biodiversity. We have a critically inadequate knowledge of the patterns and the basic processes that control the diversity of life in the sea, to choose only three examples: the microorganisms in all environments, life in the deep sea and pelagic ecosystem are all very little known.

These three ecosystems may seem unimportant but microorganisms play critical roles in the global geochemical cycles and we have all learnt and understood in the last decade that carbon dioxide concentrations are the root cause of global warming. The deep ocean is very little understood yet it occupies over half of this planet and the pelagic ecosystem away from land is home to one of the most familiar of fish worldwide—tinned tuna. You will understand the limits of marine knowledge if you realize that the worlds' largest seafood product comes from the least studied part of the ocean. We know that the largest tuna species, the blue fin, is heavily overfished and may be threatened with extinction but we do not know how many are left with any level of accuracy.

For these and almost all other marine ecosystems, we do not clearly understand how the system works and are a long way from being able to model or predict the effects of any global change or even localized damages/impacts. We understand the effects of some individual impacts to the oceans but not the ripple effects as these pass between ecosystems or areas and certainly not the combined effects of different issues. For example, do the effects of pollution and global warming cancel each other out or are they synergistic, making a bad situation worse.

The timing for reducing the loss of function in tropical marine ecosystems is critical and cannot be delayed, so while this chapter gives a brief overview of the status of tropical marine biodiversity, the emphasis is on the knowledge of species and ecosystems which is required to reduce current threats and guide policy makers towards a goal of sustainable use.

2. Key Concepts

2.1 Biodiversity

Biodiversity or biological diversity is the scientific study of nature or the natural world within a geographically defined region. Biodiversity is composed of three components, the genetic or hereditary level, taxonomic or species level, and the ecological or habitat to global level. A fourth component is sometimes included, ecological functions or eco-services, the services provided by a species that benefits humans or other species. Understanding, use or conservation of the natural world depends on our ability to uniquely name each distinct species or type of organism on the planet, so the study of biosystematics has a very important role in understanding biodiversity.

2.1.1 Biosystematics

Biosystematic or taxonomic research creates unique names for each distinct species or taxonomic group. The binomial system of nomenclature is the fundamental way to identify biological knowledge. Two words, genus + species which comprise the binomen, immediately and uniquely identifies each species on the planet. From this basic, two part name it is possible to understand how the species is related to other species and then communicate all the other known information on biology, physiology, ecology, conservation or biotechnology.

Binomens are the key to information on the 1.7 million described terrestrial, freshwater and marine species—those that have been discovered, named and classified. Unfortunately, these uniquely named species are only a small fraction of the species on Earth. Estimates of the total number of species on this planet vary from 13.6 to over 30 million. Which means, that at the most optimistic, we can only name 13% of the species on Earth. Managing the biodiversity on the planet when only 13% are known, is like trying to locate a small but vital company in New York using a phone book with 7 from every eight pages torn out. We know the names for the big, common things but not the small obscure ones. No manager could run a complex company if the names, functions and products of 87% of the staff were unknown. As unwitting mangers of the biodiversity of the world, we have changed the functions of significant parts of the planet yet we only know the names of one part in eight. When we do not know or understand the function or interactions between 7/8 of the natural systems which sustain the planet, is it any wonder that we cannot predict the effects our "globally significant changes" are having.

There are several estimates for the known number of marine species; coral reefs contain 93 000 and the total exceeds 274 000 known species. When detailed collections are made in one area for any of the less studied groups (especially the smaller micro plankton or the meiofauna) it appears that 85–90% of the species are unknown. Yet these small organisms are responsible for the function of fundamental ecological processes and are essential components of oceanic food webs. These groups are involved in ocean wide biogeochemical cycles for oxygen, nitrogen, carbon, phosphorus and others. In the last decade we discovered the photosynthetic bacterium, *Prochlorococcus.* One of the smallest species turns out to be the most abundant primary producer in the sea, which produces up to 80% of the total local primary production. An abundant, critical link that was simply not known. The best information available suggests that there are a total of 1.85 million marine organisms but there could be many more if the estimates of species richness in the deep ocean are confirmed. Marine organism biodiversity estimates of 15% named are therefore very similar to the total planet estimate of 13% named. Certainly with this small percentage of named species and even fewer whose functions are precisely known makes managing marine resources and attempting to conserve marine biodiversity more guesswork than science. How many other critical species like *Prochlorococcus* have yet to be discovered?

2.1.2 Genetic Biodiversity

Genetic level biodiversity is very little studied in the ocean. The differences between individuals or sub populations are little known but may be very important for bio-extraction of chemicals in the future. For example, red algae contain alginate chemicals used in toothpaste, medicine and cosmetics. Seaweeds are farmed for this product and it clearly makes sense to use the seaweed population which produces the most alginate. For this reason, the gene that controls or modifies alginate production has significant economic value. We know that that genetic diversity is one of the primary weapons species have against disease or environmental change, so it makes good sense to protect the maximum genetic biodiversity of red algae to maintain production of alginates in a time of global warming.

As fish stocks disappear so does their genetic distinctiveness and the consequent adaptations to local conditions, physical and environmental. Fish stocks in the Caribbean Sea have responded to heavy fishing pressure by a genetic shift towards a smaller maximum size and a smaller size at first maturity. The genetic diversity which is most desirable for fisheries and aquaculture is disappearing as fast as the large, fast growing individuals. On land, there is increasing concern about genetically modified foods having effects on natural biodiversity. In the ocean, this is already a fact of life as farm bred, genetically modified, fish species escape and interact with wild stocks.

2.1.3 Species Biodiversity

At the species level, life is very much more diverse in the sea than on land. The land has more species (mostly insects) but life in the sea is richer in the more distinct forms of life. There are no jellyfish, corals, starfish, shrimps, sea squirts or octopus on land. These higher taxonomic classification levels are more genetically distinctive and the extinction of a single species such as the coelacanth *Latimeria chalumnae* which is the only member of an entire subclass, would mean the loss of a completely unique amount of genetic diversity.

A number of marine species have been hunted into extinction, Stellers sea cow *Hydrodamalis gigas*; the Atlantic gray whale, *Eschrichtius robustus*; the Great Auk, *Pinguinus impennis*; and at least 10 other seabirds. We know of two smaller invertebrate species that have been made extinct— the western North Atlantic eelgrass limpet, *Lottia alveus*, and the San Diego mudsnail, *Cerithidea fuscata.* This is however not a true picture, data for most species is simply not available. We do not know whether several dozen species are extinct because there is simply too little data. The biodiversity surveys that have been conducted are so irregular and separated in time and space that it is impossible to detect extinction. For example, what other species coexisted with the western North Atlantic eelgrass limpet or the San Diego mudsnail and were never described before they became extinct? The coelacanth, known from a few specimens from the Comoros islands, East Africa was discovered recently in an Indonesian fish market. Does this discovery mean that the species is common but not known? Or are these the records of the last few individuals of a widely dispersed species?

The giant clam *Tridacna gigas* exists as ten known individuals in all of Sabah, East Malaysia. (All giant clam species are protected by law but are available in most seafood markets or restaurants.) The few *T. gigas* clams that remain alive are too far apart to breed so they are genetically isolated and therefore functionally dead. The species is obviously not quite regionally extinct: yet! These are large, comparatively well-known species; with the pollution and other disturbance to ecosystems which has occurred in the last 25 years we expect that the number of marine extinctions is much greater than the few species mentioned above. Studies on species-area curves indicates that loss of 90% of a habitat will involve loss of 50% of the species. This means that the loss of 84% of the mangrove forests in Kalimantan (Indonesian Borneo) or 95% in the Philippines suggests that 30–40% of the mangrove forest species are extinct. We cannot confirm that this has occurred because we have not recorded or named most of these species, let alone determined population size before the mangroves were destroyed.

2.2 The Marine System

Life in the sea is fundamentally different from life on land and before we can understand the issues and changes that face marine ecosystems we need to change our mode of thinking to deal with an alien environment. Crustaceans, starfish and sharks may have developed on the same planet as humankind but the environment they live in is completely different. All marine organisms have properties which differ so much from our own that dealing with life in the sea in the same way as life on land simply does not work! Marine and terrestrial ecosystems differ in significant ways that have important implications for understanding biodiversity, ecosystem change and implications of management.

The most critically different of the attributes of the sea is its buoyancy. Organisms are supported and exist in a four dimensional medium. There is life from the bottom to the top of the fluid but most organisms can control only their depth in the sea. Position and location are relative to other objects in the fluid changes because the environment is constantly moving. Time, the fourth dimension becomes critical because reproductive products—eggs and larvae—are subject to fluctuating ocean currents and can travel in different directions depending on time of release. There are very few marine organisms that do not travel 100s to 1000s of kilometers in every lifetime. This makes management using human views of territory and distance complex or even impossible. These and other unique attributes of marine ecosystems are listed in Box 1.

• Marine animals are buoyant which makes both large and small organisms subject to fluid transport processes which do not occur on land. Most marine organisms regardless of size are transported 100s to 1000s of km during their lifetime.

• Marine primary producers are represented by small and often mobile phyla. Terrestrial producers tend to be large and sessile. Marine producers can be spatially mixed, and can unexpectedly produce blooms that may be toxic.

• Distant marine habitats can be linked by dispersing larvae. Such systems are "open," and connections between the water currents, water chemistry, benthic and planktonic life-history stages assume great significance.

• Large marine carnivores and grazers—top predators such as fish, crustaceans or starfish—have a greater range of life-history characteristics than terrestrial equivalents. They have mobile planktonic and less mobile benthic life stages, each with unique environmental responses.

• Marine organisms often have very high reproductive potential but survival is controlled by recruitment and mortality, especially at small sizes. This may buffer them from extinction due to overexploitation, but it also renders their populations far more variable and less predictable and makes them more vulnerable to threshold effects.

• Marine organisms are frequently hermaphrodite with sex changes at large sizes. Fisheries with heavy selective pressure on the larger sex have resultant significant effects on reproductive ability of the population.

• Marine organisms are often very old; turtles, lobsters, and some fish are all capable of living and reproducing for well over 50 years. Old marine animals are large and produce many more larvae/offspring than smaller adults which means that fisheries-capture of a few large individuals can have disproportionate effects on the reproductive success of the whole population.

• When ocean and continental (aquatic and terrestrial) systems are compared, biomass is found to be thousands, to hundreds of thousands of times more dilute in the oceans, the oceans are on average several to hundreds of times less productive than the continents.

• Oceanic species interact trophically with more other species than continental species, the largest marine predators and prey are larger by one or two orders of magnitude than the largest creatures on land.

• All life originated in the sea, the higher order diversity of marine life is substantially greater and there are 13 unique marine animal phyla (whereas there is only one unique land phylum). The existence of such a large number of unique phyla provides a compelling argument for the importance of the evolutionary history of life in the sea.

Box 1: Significant differences between marine and terrestrial ecosystems

When the fluid nature of marine ecosystems is considered, it is immediately apparent that a regional scale approach to problems is needed involving multiple separate sites within an appropriately sized geographic region. For example, the coral reefs of the South China Sea appear to be maintained on a 3–4 generation cycle. Larvae produced on reefs in the Philippines drift with water currents to Thailand, Vietnam, or China to settle grow and mature. From these northern and western reefs the next generation drifts to the Spratly islands and the southern reefs. A further generation and the larvae drift back to the Philippines to complete the cycle. While some local recruitment probably does occur, it is clear that to maintain the genetic and species diversity in reefs throughout the South China Sea a whole series of protected areas linked by the ocean currents will be needed.

Marine turtles are also a good example of large-scale dispersal. The males and females aggregate to nest at the beach where they hatched 50 or more years before. The Green turtle (*Chelonia mydas*) nests on a small number of beaches worldwide and shows strong homing to the natal nest. Hatchling turtles disperse rapidly and the adults from several different populations are all found on one feeding ground. Adults which nest in countries as far apart as Malaysia and Australia are all found feeding on seagrass beds, or being caught for human consumption, in Indonesian waters. Obviously, protection of nesting beaches in one country is not enough! To effectively protect turtles, all life stages must be included and this means that transboundary and regional solutions are also needed.

Central to this theme of ecosystem differences between terrestrial and marine ecosystems is the need for all management to be concerned with the big picture, the regional setting and the parts of the ecosystem which occur outside the jurisdiction or management area. Florida bay in the southern USA is a good example of a coastal zone/estuary system that demonstrates that the origins of profound biological changes at one site require understanding similar or related changes within the region.

There is growing evidence and understanding that the Florida Bay ecosystem is collapsing. The Florida Keys and Florida Bay (2,200 km^2) are the only tropical marine ecosystems in the continental United States and are very valuable (economically, socially and aesthetically) for a wide range of human activities. The bay is an estuary with many rivers and it is affected by alterations to land runoff and freshwater systems as well as by marine processes. The adjacent coral reef tracts of the Florida Keys are connected by coastal currents, and thus the water masses in the bay have a critical influence on the reefs.

- Nutrient loads have increased as a result of sewage and other terrestrial runoff, which has led to a large increase in the occurrence of algal blooms. These blooms frequently spread to the coral reefs of the Keys, where they can kill a wide range of species.
- Freshwater inflow from the Everglades has been reduced and hypersalinity in eastern Florida Bay is common. As a result, the communities of water birds and fish which depend on the freshwater inflow are significantly reduced. Commercial game fish populations are reduced because of the juvenile requirement for estuarine conditions.

- The majority of the bay is covered with seagrass and in the late 1980s it was noticed that the seagrass was dying. By 1993, this seagrass mortality had affected 18% of the Bay.
- The commercial catches of valuable pink shrimp have fallen dramatically. The cause of this is difficult to pinpoint but the fact that the shrimp spend their juvenile stages in Florida Bay with less seagrass and less freshwater are probably contributing factors.
- Large sponges, important for spiny lobster habitat, have also declined.

The causes of ecosystem collapse in Florida Bay are difficult to identify but it is clear that a synergy between, habitat destruction, terrestrial pollution and other local effects are being imposed on a system which is already suffering from broader scale changes in the Gulf of Mexico and the Caribbean. In the Gulf of Mexico, there is a huge seasonal area of the seabed that becomes anoxic (without oxygen) every year. Eutrophication, oxygen demand from decomposing sea-life, and mortality of photosynthesizers can be involved in anoxic areas. Anoxic areas of the seabed also reduce oxygen availability by increasing chemical demand. Pollution from fertilizers, herbicides and pesticides which wash down the Mississippi river from the American agricultural industry as well as human and animal sewage are thought to be the main cause.

In the Caribbean Sea and the Florida Keys there has also been a dramatic coral loss on many reefs and its replacement by algae. Jamaica in the Caribbean Sea is a typical example. From historical records the largest herbivores; green turtles, manatees, parrotfish, and conch snails were severely decimated by the early 1900s. By 1959, surveys were reporting that the pot fishery for reef fish was only capturing juvenile fish, and reef herbivores were dominated by the algae-eating sea urchin *Diadema antillarum*. A series of hurricanes in the 1980s seems to have tipped the balance and the ecosystem spun wildly out of control. The *Diadema* sea urchin numbers increased dramatically after the hurricanes only to fall a few years later when a pathogen caused massive mortality of the sea urchins. With nutrient enrichment from near-shore development and few herbivores to control algal growth, the algae populations were able to out-compete and overgrow the corals. The system now appears to have stabilized as an algal dominated environment with few herbivorous fish or sea urchins and very limited coral growth.

The experience in Florida Bay and the Keys shows that while ecosystems can resist local damage on a large scale, the cumulative and synergistic nature of all applicable stresses from inside and outside the area are probably irreversible within one or even more human generations. Clearly the most important lesson from the situation is that understanding and managing the whole watershed is essential if the issues that impact the ecosystems are to be rectified or controlled.

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