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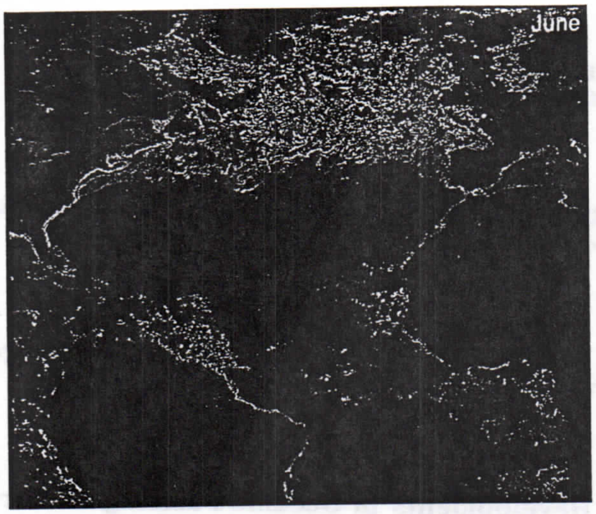
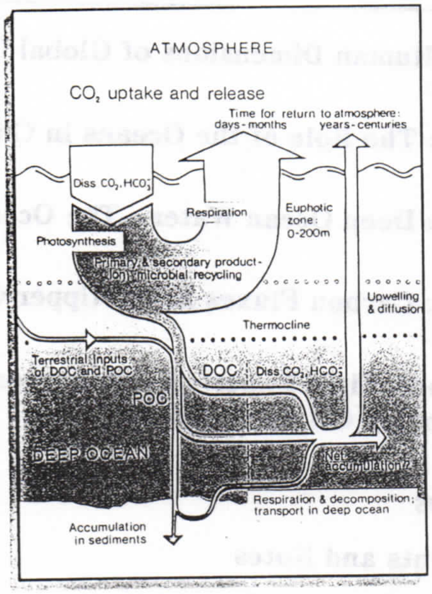


Global Change, Part II



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GLOBAL CHANGE, PART II

Guest Editor:
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Front Cover
Diagram: CO_2 taken up by phytoplankton; most of the CO_2 is returned to the atmosphere within a few weeks. DOC, dissolved organic carbon; POC, particulate organic carbon. See page 60 for discussion. Source: Phillip Williamson, Joint Global Ocean Flux Study, International Geosphere-Biosphere Program. *Satellite Images:* Development and intensity of phytoplankton growth (or "spring bloom") in the North Atlantic basin during 1979 as shown by the Coastal Zone Color Scanner (CZCS). Source: Gene Feldman, Space Data and Computing Division, NASA Goddard Space Flight Center.

Back Cover
Bottom: Flash flooding northwest of Asheville, North Carolina. Photo: Grant W. Goodge, Positive Giant Photography. *Top:* NORAID pier built at Lake Turkana in Kenya in the early 1970s; when built, the pier had water within 3 ft of its top. Photo: Thomas C. Johnson, Duke University Marine Laboratory.

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Biological Diversity and Neptune's Realm

PAPER

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ABSTRACT

The diverse biological life in both terrestrial and marine environments offers mankind many practical and potential resources. These natural pools of wealth are under continuous pressure from various humanly induced alterations. Areas of current research are attempting to challenge the assorted problems, but many of the issues have yet to be addressed fully. Global climate change and soaring extinction rates appear to be the consequence of anthropogenic effects. Important preventive action is needed to restrict the forcing mechanisms for climate change being created by altered atmospheric composition.

INTRODUCTION

One of the astonishing characteristics of life on earth is its very diversity. Approximately 1.4 million species of plants and animals have been described by scientists, but the inventory of life on earth is so far from complete that it is difficult to state within an order of magnitude how many species actually exist (Wilson, 1985). From within this uncertainty, broad patterns emerge. On land there are clearly gradients of increasing diversity as one approaches the equator, particularly in the wet areas where the remaining tropical rainforests flourish. In the seas, coral reefs are especially conducive to great species diversity.

The diversity of life on earth is being reduced by the combined effects of human activity. Species loss is nothing new of course, but modern extinction rates are about a thousand to ten-thousand times more than the normal "background" rate (Lovejoy, 1980; Wilson and Ehrlich, 1991; Arroyo et al., 1991). The causes fall into five broad categories, all of which are serious problems: pollution, over-exploitation, physical destruction, alien species introduction, and climate change.

The greenhouse effect and global climate change present a terrifying specter from the point of view of biological diversity conservation (Peters and Lovejoy, in press). Climate change is not new and has occurred naturally throughout the history of life on earth. Certainly biota have, by and large, adapted to glacial and interglacial climate swings (Davis, in press). Projected rates of climate change, however, tend to be faster than any species has been able to adapt to in the past. Even if species are capable of tracking their required climatic conditions quickly enough, on land this will have to take place in landscapes highly modified by humans. We have essentially created an ecological obstacle course where we are instigating a biotic race for survival at unprecedented speed.

DIVERSITY: PROMISES AND PROBLEMS

The bulk of the world's animal diversity consists of the invertebrates. On land they are dominated by the Insecta, whereas in the sea, there is unmatched variety of invertebrate taxa of "higher" levels of organization, and only a handful of insect species occur at the very margins of the oceans. Of all the major divisions of plant and animal kind, almost every one is represented in the oceans, and some are found exclusively in the marine environment. On land only about half of all the major divisions are represented.

Discoveries in molecular biology have demonstrated a remarkable uniformity in the ways living systems work. This uniformity has, however, tended to obscure the enormous variety of systems and processes among organisms and the amazing richness of information about living systems. E.O. Wilson (1988) has calculated that the amount of information in a single chromosome of a mouse is equivalent to all the information in all editions of *Encyclopedia Britannica* combined. So, the loss of a single species clearly represents a major loss of valuable information. This information content of biological diversity is a profoundly important reason to concern ourselves with soaring extinction rates. Other than archeology and anthropology, the biological sciences are uniquely beset with the loss of the very material upon which knowledge is built. One can imagine the reactions of chemists and physicists if a major portion of the periodic table were to be randomly removed.

The terrestrial and marine environments have evolved unique systems that are complex yet fragile, and we have just begun to explore the potentials and wonders within these two worlds. Clearly, major surprises remain to be revealed in organismal variety and their potential contribution to human societies. Humans have been only once to the deepest part of the ocean, the Mariana Trench, but have walked on the moon six different times. Even with today's advances in modern technology, less than 10 percent of the oceans have been actively sampled. Almost every time a submersible ventures to a hydrothermal vent or other great depth, new species are discovered. In recent years we have learned that specifically adapted organisms can live at temperatures in excess of the boiling point of water and that entire biological communities can exist by depending on the primal energy of the earth. The hydrothermal vents represent one of the harshest environments on earth due to the absence of light, the exposure to extreme temperatures and pressures, and the high concentrations of hydrogen sulfide. Prior to these discoveries, the vent regions would not have been considered a place where life could exist. As we explore life on earth, what is biologically possible, to a great extent, remains to be discovered.

BIOLOGICAL DIVERSITY ON LAND

On land, extinctions have reached crisis proportions. As the human population has grown to 5.4 billion, an enormous amount of habitat destruction has taken place. In Western Ecuador, for example, 96 percent of the forest below 3,000 meters has been cleared, leaving only isolated remnants. These isolated forests are under enormous pressure as the sole haven for a variety of plant and animal species. Tropical forests, which probably harbor over 50 percent of all species on earth, are already half gone and, according to a recent conservative Food and Agriculture Organization of the United Nations (FAO) estimate, are vanishing at a rate of 42 million acres a year.

Over and above the threats to biological diversity caused by habitat destruction, there are further problems inherent in the health and fragmentation of the remainder. Isolated fragments of once continuous habitat are dynamic entities that change as a consequence of isolation, losing species and simplifying over time (Lovejoy, 1980; Wilson and Willis, 1975; Terborgh, 1974). Additionally, they are subject to increasing amounts of pollution and environmental degradation.

The extent and rate of species loss are invariably related to the size of the isolated fragment. The likely cause of the loss of various mammal species from western U.S. national parks is that the protected areas are simply not large enough (Newmark, 1987). Such is the case in the sagebrush habitats of canyonlands in the increasingly urbanized San Diego area (Soulé, 1991). This problem is also being studied systematically in the central Amazon north of Manaus. There, the Minimum Critical Size of Ecosystems project (Lovejoy, 1980; Lovejoy and Bierregaard, 1990) is in the process of confirming the importance for biological diversity of large reserves versus a series of small ones of the same total area.

There are even more frightening implications for further extinction on land where biological diversity is increasingly confined to isolated areas of remaining natural habitat. There, with the biotic eggs in a single basket, biological diversity is particularly vulnerable to problems emanating from without; acid rain is but one example. We live in a world where lead originating from Japan appears in precipitation over the Great Lakes, and DDT shows up in Antarctic penguins. Many of these problems, and most of the extent of their negative impact, is not understood. There are analogous marine situations, for example, how an oil spill affects a sanctuary. These are examples that, in our view, present a grim prospect for much of the terrestrial biota, though one that is almost impossible to avoid. The only solution is to stop the anthropogenic pollution activities as well as the forcing mechanisms for climate change being created by altered atmospheric composition.

NEPTUNE'S REALM

The outlook for biological diversity in marine environments is far less clear. To start with, we simply know less about the marine environment. The oceans play an important, but not fully understood role in the global climate and biogeochemical cycles, such as that of carbon. Perhaps less appreciated is the role marine biological systems play and have played in the global carbon cycle. An important pool of carbon has been accumulated over geological time as marine planktonic organisms have built calcium carbonate exoskeletons, many of which sink to the seafloor and become transformed into geological formations, such as limestone. Indeed city dwellers can view fossil marine biological diversity in marble and other marine-formed building materials—an exercise that can be termed paleoecotourism. Whether coral reefs are an active sink of carbon is not clear, but they may capture as much as 2-4 X 10^9 metric tons annually. However, the chemistry balance in the water column is also changed in the process and this effect has yet to be fully modeled (James Porter, personal communication).

The biological diversity of oceans can provide many resources of present or direct future use to human society. The various fisheries of invertebrates and fish themselves are obvious examples. The value of *frutta di mare* is underscored by recent rapid developments in mariculture. Many marine products are found in common foods and household items, such as agar from seaweed, which is often used in making ice cream and shampoo. Another example includes *Hermissenda crassicornis*, one of the group of marine snails without shells known as nudibranchs, which is considered of sufficient importance to be accorded a full-page portrait in the recently issued report on the U.S. government initiative, The Decade of the Brain. This nudibranch's simple nervous system provides an excellent model for studying and identifying basic principles of learning. Science needs more than organisms that serve as surrogates for studying humans; science needs organisms to provide perspectives on human biology not accessible through direct studies of people or their close analogs.

Science has just begun to explore the possibilities of medicines from the sea. Over thousands of years of evolution, organisms have developed intricate physical and chemical defense mechanisms. The physical devices, such as seashells and shark jaws, provided early humans with materials for tools, weapons, and goods for trade; the chemical defenses offer modern science a pharmaceutical potential. New structural compounds are being discovered on a continual basis. Many have no current direct medicinal value, but they still may offer unique templates for organic chemists to exploit in designing new drugs. An article in a previous issue of the *Marine Technology Society Journal* (Betz and Marderosian, 1991) dealt with a study of antimicrobial activity in marine organisms. Of the forty species selected from twelve phyla, thirty showed activity against one or more of five disease agents tested. It is important to note that most of the drugs used today were originally discovered in their organic form. This alone is a powerful justification for the preservation of species.

The contributions from terrestrial ecosystems, particularly forests, have long been appreciated in regulating local watersheds. The Panama Canal would suffer millions of cubic meters of siltation annually were its watershed to be stripped of its tropical forest. Similarly, the filtering activity of marine organisms is monumental in their local environment. Today in the Chesapeake Bay estuary, oysters alone pump a volume of water equal to the entire bay once a year. Prior to the collapse of the oyster population, the oysters pumped a similar volume *once a week* (Horton, 1991).

There appear to be far fewer barriers to species dispersal in ocean environments compared to land environments. However, there are very strong barriers in the oceans defined by light penetration, currents, temperature, nutrient availability, depth and pressure, oxygen concentrations, physical land barriers, pH, salinity, and physical objects around which many organisms colonize. These barriers are in constant flux and are continuously interacting to define the parameters of the habitat. When even one of these variables is altered, entire systems can collapse. The marine environment is very susceptible to the five humanly induced alterations.

Much of the known endangerment of species in the marine environment comes from deliberate target harvesting of particular species. This is generally the story of most marine mammals, but also some fish species, such as the bluefin tuna and various shellfish, can be endangered by over-exploitation. Often it is larger and older fish, the most efficient reproducers, that are harvested first. This only compounds problems of repopulation and maintenance for a sustainable harvest. It is interesting that on land humans tend to harvest herbivores whereas in the sea humans tend to harvest carnivores (Gorden Orians, personal communication). This probably has different implications for terrestrial versus marine food chains.

Noise pollution, such as the sporadic noises generated by ship engines, may cause biological problems. The ability of humpback whales to communicate across entire ocean basins (Payne and McVay, 1971) depends on the propagation of sounds in the frequency range of 20 Hz through conductive ocean layers. This may allow social contact among what otherwise appears to be a widely dispersed population. The noise produced by modern ship traffic greatly increases background noise within the critical frequencies for the whales. There are implications for their social behavior from the reduced communication distance. It is uncertain how this reduced communication distance might compound with low population size and attendant reduced genetic variability caused by overharvesting.

The effects of humans on biological diversity are most apparent in the coastal zone. The open ocean is relatively clean, however, most organisms live in the polluted waters fringing continents and islands. The decline in the Chesapeake oyster population is a good example of the loss of a species ecological role, which could be called an ecological *extinction* were this to occur throughout the entire range of the organism. The biologically diverse marine communities most obviously vulnerable are the world's coral reefs. Smithsonian scientist Jeremy Jackson has noted severe damage to coral from oil spills and secondary susceptibility to diseases for years thereafter. In addition to the direct physical damage caused by boaters and thousands of tourists, the reef systems in the Florida Keys are being threatened by sewage runoff. Development and deforestation take a particularly heavy toll by generating sediment that washes down and essentially smothers delicate coral organisms. In comparison to other sources of damage, the sheer destruction of habitat from dynamiting, coral harvesting, anchoring, and ship groundings are perhaps easier to control.

Sudden elimination of natural barriers which would allow biotic interchange can create environmental havoc. Such would be the case if we built the proposed sea level canal by removing the isthmian barrier between the Pacific and the Caribbean. Species would be introduced primarily from the Pacific to the Caribbean because of differential sea levels on either side of the isthmus. The potential biotic impoverishment is an overwhelmingly important reason not to build a sea level canal—unless the separation currently provided by a freshwater canal is provided by another failsafe mechanism. Another means for exchange of exotic species is the daily release of ballast from large cargo ships. Thousands of gallons of seawater with all the various suspended macro and micro organisms are delivered to previously inaccessible areas. The environmental impact of these releases is difficult to quantify, but there are several examples of an introduced organism reducing or eliminating endemic species. This dilemma affects land as well as the aquatic environment. Problems arise from the introduction of microorganisms to new areas. The prime suspect for the mass mortality of *Diadema anthillarum* (a sea urchin) in the North Atlantic is a pathogen that may have been artificially introduced. Other outbreaks include high mortality rates of coastal dolphins with no obvious responsible pathogen. New distribution patterns for viruses and bacteria can have effects but to what extent is unclear.

Human-induced pollution enters the environment through several different pathways. Point source discharges from industrial waste, oil spills, and human sewage are the easiest to quantify and control. Small but daily releases of non-point source pollutants can add up to major problems. Runoff from agrochemicals, atmospheric deposition of toxins, and storm drain runoffs that transport thousands of tons of plastic debris and medical waste into the sea are all examples. More oil enters the aquatic system from the dumping of used motor oil down the drain than from large oil tanker spills. Various types of waste often contain toxins or infectious microbes. The daily release of human sewage containing high concentrations of nitrogen and phosphorus causes an overload of otherwise limiting nutrients and can result in planktonic blooms. When the plankton die and sink to the bottom, bacteria break down organics and can create anoxia. In an enclosed body of water this problem can be even more concentrated.

Estuaries act as nurseries for the sea because many organisms, including those of economic importance, spend their juvenile stages in the protected shallows to avoid larger predators. Due to development and non-point source pollution, these areas are under great stress because they tend to focus all pollutants in one small and relatively contained body of water. The protection of these wetlands is essential for the fishing industry that is just now recognizing the direct connection between coastal zone management and open ocean fisheries. The United States alone has already lost over 50 percent of its coastal wetlands.

The sea surface is one of the more biologically diverse realms. There, a thin layer holds an astonishing variety of organic compounds and tiny living organisms, known collectively as *neuston* (from the Greek word for floating). This area as a whole, now known as the sea surface microlayer, includes microalgae, fish eggs, larvae of various sorts, and many other organisms.

This surface microlayer appears to collect metal ions and man-made pollutants, such as pesticides, at much higher concentrations than the rest of the water column. Practically nothing is known of the consequences except that some larval stages seem to be affected seriously (Hardy, 1991). An additional variable is the possibility that sulfide gases produced by the seasurface microlayer may be a very significant source of nuclei for cloud formation and hence may contribute to the regulation of global temperatures and climate. How all of this is affected by anthropogenic effects is unknown but very important. Another environmental stress for the microlayer is the increased exposure to ultraviolet B radiation due to large holes in the protective ozone layer over both the Arctic and Antarctic. Increased radiation has affects on the DNA integrity and many of the biological processes of phytoplankton, such as photosynthesis and nutrient uptake (Weiler, 1991). These primary producers are the first part of a complex system with several trophic levels and they can affect the whole system.

Of particular concern is a pathology known as coral bleaching. About 40 percent of the algal-bearing corals in the Caribbean lost their pigmentation in 1987, and there was extensive coral bleaching in the eastern Pacific coinciding with the 1982-1983 El Niño warming (Porter et al., 1989). The probable cause is elevated water temperature in excess of 29°C. The causal mechanism has not yet been proven, but it seems likely that the response of polyps under elevated temperatures disrupts rhythmic contractions which in turn causes the symbiotic zooxanthellae to be ejected (Leo Buss, personal communication). Without their photosynthetic elements, corals cannot survive for an extended period. If this proves to be the case, corals may be one of the best early indicators of global warming trends and, in turn, would affect the great diversity of reef dependent organisms.

The first cases of species eliminations in corals have been documented in the eastern Pacific (Glynn and de Weerdt, 1991). Two Panamanian species with small ranges disappeared as a consequence of the 1982-1983 El Niño effect. One species of *Millepora* is not known to occur elsewhere despite extensive searching; the other, *M. Platyphylla* is known only to occur to the west of the study site.

OTHER CLIMATE CHANGE EFFECTS

Other effects of climate change will be seen in coastal zones. As ice melts and seawater expands, sea level will rise. A major portion of the world's human population lives along the coasts and will be directly affected by increased flooding, coastal erosion, and property loss. Climate change will also allow saltwater intrusion into aquifers and cause changes in salinity gradients for estuaries and bays. Further, human occupation and modification will impede the natural shoreward recession of estuaries and wetlands (Reid, 1991).

More speculative but no less worrisome is the extent to which climate change may alter wind patterns. Surface ocean currents are to a large degree wind driven so there is potential for major change in both currents and regional climates. Changed wind patterns will have a direct affect on upwelling patterns, which in turn will change the pattern of biotic distribution (Bakun, 1990). Other consequences include altered rainfall patterns that could have economic as well as epidemiological implications.

CONCLUSION

If all human driven vectors of change are taken together, the prospects for biological diversity are darker than they have ever been in our history. It is clear that an important and relatively simple first step would be to augment greatly biological inventory on land and sea. We do not, however, have the luxury of taking the linear approach of leisurely (or even rapidly) completing an exhaustive inventory of the biota. Rather, strong action needs to be taken immediately based on current knowledge of threats to particular biota. Exploration and action must proceed simultaneously in an iterative process in which expanding knowledge results in even more informed action. Above all, preventive action is needed to stop global climate change, the greatest threat of all, from proceeding any further.

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