Danger At Sea: Our Changing Ocean

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FORWARD: THE WATER PLANET

"How inappropriate to call this planet Earth, when clearly it is Ocean. " -- Arthur C. Clarke

Current excitement about the possibility that life may exist beyond Earth's atmosphere is focusing attention on the primary ingredient required: *water!* Water - and lots of it - is necessary for life to prosper on this or any other planet. *While there can be water without life, no life is possible without water.* The 1997 discovery of abundant, possibly liquid salt water on one of Jupiter's moons, Europa, has prompted speculation that living creatures may exist in the reddish icy slush observed by high flying instruments. Headlines announced in 1996 that squiggly marks on a four billion years old rock from Mars provided evidence that life may once have thrived *there;* there is even speculation that the red planet in the past might have been blue with an *ocean,* perhaps green with plants.

Meanwhile, the life-giving ocean on ***this*** planet has been getting short shrift from humankind. While it is widely acknowledged that life on earth began in the sea and still provides more than 95 per cent of the biosphere; that the ocean shapes the nature of climate and weather, stabilizes temperature, generates most atmospheric oxygen and generally makes earth hospitable for tender, air-breathing humans, there is at the same time a curious notion that the sea is so enormous that nothing we can do can possibly harm its basic nature. As a consequence, a profound and dangerous complacency lulls us as anthropogenic changes of geological magnitude alter the nature of ancient ocean ecosystems.

Change, of course, is normal. Since earth first was touched four billion or so years ago with life, the planet has undergone stupendous changes -- some brought about by grand processes involving pulses of energy from the sun, shifts of the magnetic poles, the tilt of the earth, impacts from comets, meteors and other matter from space. Ice ages have alternated with times of global warming; continental masses have moved, volcanoes erupted, earthquakes have shattered ancient mountains and changed the course of rivers. Species have come and gone; entire categories of creatures, once abundant, have been displaced by others more favored by new environments. This can hardly be termed "stable, " yet, conditions on earth have remained within a remarkably narrow range for millions of years -- narrow as compared to say, the conditions on any other planet in this solar system -- or elsewhere in the universe, where extremes of temperature prevail and liquid water and gaseous oxygen and carbon dioxide are in short supply.

Knowing that we are dependent on keeping earth more or less as it is in terms of life support functions, it makes a lot of sense to figure out whether the swift changes we are witnessing -- and causing -- in recent decades, may set in motion events with undesirable consequences. It would be useful to know, for example, to what extent chemicals that we have released into the atmosphere in our lifetime may have decreased atmospheric ozone causing radiation to kill phytoplankton in Antarctica, perhaps resulting in a food shortage for krill and other zooplankton, and thus lean times for squid and fish, birds, whales, and seals. Could such a reduction in energy fixed from sunlight translate in due course to lower levels of nutrients flowing via deep northbound currents from Antarctica to the coast of Peru and elsewhere, trigger a change in populations of fish there -with economic as well as environmental repercussions? Might the millions of tons of wild creatures removed from the sea worldwide in recent years disrupt the way natural systems function? Might the redistribution of protein and other substances taken from ocean ecosystems significantly alter the basic chemistry of the planet? Could it be that millions of tons of chemicals not found in nature and huge quantities of excess fertilizers flowing into the sea via sewers, rivers, and ground water might alter the way certain systems behave? Does it matter? Should we care?

For millions of years, our species could do little to influence the character of ancient ecosystems, but as our technological powers and sheer numbers have exploded -- from one billion people in 1800 to two billion in 1935 to a projected six billion by the year 2000 -- so has our impact. We, not an ice age or a wayward comet, are responsible for the swift decline of more than 100 popular marine fish and numerous other ocean creatures in the past two decades. The number of marine species that have been exterminated by unwitting human actions in the same time may be in the tens of thousands. What is lost cannot be recovered, but we can -- and we must -- change our ways to protect and restore what remains of the natural systems that sustain us, if we are to prosper as a species.

In the study that follows, the importance of the living ocean to humankind is clearly articulated, with values ranging from obvious economic returns that most people expect to the hidden but vital services that many take for granted There is also a nerd look at what we are doing to jeopardize natural systems including overfishing, destructive methods of removing wildlife from the sea, pollution, and flawed policies that have an overarching influence on human behavior. Finally, there is a well-reasoned analysis about how we got to the present state -- and what might be done to turn things around. The underlying message is that we have the power to do so. The challenge is to use it.

-- SYLVIA A. EARLE

THE OCEAN

Earth is a water planet. The ocean covers seventy-one per cent of the planet's surface and, given its depth, accounts for over ninety-five per cent of its life-supporting space. Life on Earth began in the ocean; more than 3.5 billion years later, the ocean and atmosphere are engaged in an interplay that continues to make continued life on Earth possible.

The ocean is a living, salty soup; every spoonful contains life, from the deepest trenches to the coldest frozen seas. In fact, the widest variety of life forms is found in the ocean, not on land. There is no place in the ocean where life is absent.

The ocean is the engine that drives our planet's climate systems. Without the ocean, Earth would be intolerably hot during the day and frozen at night. The ocean absorbs and a store heat energy from the sun’s rays and redistributes it around the globe, affecting the movement, temperature and moisture content of air masses over sea and land.

We all need and use the ocean. Whether we live in Maine or Montana, New York or Nevada, the ocean has a vital influence in everyday life. Not only does the ocean contribute an estimated 70% of our oxygen but it also removes a significant amount of carbon dioxide from our atmosphere. Two-thirds of the world's human inhabitants live within 40 miles of the ocean. Fish from the ocean provide the principal source of protein for one-sixth of the people on Earth. The rain that falls, the waters we drink and bathe in -- all are inextricably linked to the ocean.

Marine ecosystems are characterized by a diversity of important functions as well as a diversity of species (1). Sea grass meadows are protective nursery areas for many estuarine and ocean fish. Healthy estuaries are a rich source of nutrients and food organisms that support their own high productivity and that of adjacent coastal waters, and often supporting valuable fisheries as a result. Some coastal areas are abundant sources of larvae that are transported by currents to other areas where they replenish depleted populations -- which may include populations of commercially valuable shellfish. Marshes trap sediments and filter nutrients and chemicals from the water -- a function that may help protect coastal waters from some of the pollution that humans allow to flow from the land. Coastal upwelling areas provide nutrients for highly productive food webs that support other sea life and humans. Coral reefs provide physical structure, food, and protection for a great diversity of marine species, and the coral itself is composed of carbonate which has been produced by animals and plants in a process that sequesters large quantities of carbon dioxide from the environment.

It is apparent that some of the functions of marine ecosystems happen to have special value to humans, and, as a result, some economists have attempted to determine their worth in dollars (2). However, it is important to also appreciate that these functions are essential or useful to supporting a healthy ocean system in its entirety and contribute to the support of all life on earth, regardless of any direct monetary value to the human species.

A CHANGING OCEAN

The ocean has long been widely viewed as limitless, immune to human activity. As recently as 1956, a marine scientist wrote that:

It may be rash to put any limit on the mischief of which man is capable, but it would seem that those hundred and more million cubic miles of water ... is the great matrix that man can hardly sully and cannot appreciably despoil (3).

Yet, now, it has become evident that the ocean, for all its vast dimensions, can be significantly altered by human activity. Most notably, this is taking place along the coast, a narrow yet highly productive transition zone that connects land with ocean, and which consists of a multitude of distinctive environments such as maritime forests and dunes, beaches and rocky shores, and wetlands such as sea grass meadows, salt water marshes, tidal flats and mangroves.

But human impacts are not limited to coastal areas, no less than the activities that cause them. From the coastal zone to far inland, the lifestyles of our growing numbers and the industries that support us affect coastal and marine environments from the edge of the land and beyond, into the deep ocean.

Across the United States and around the world, the increase in population and consumption, and the concomitant growth of commercial, industrial and recreational activity continues to promote environmental change and degradation. The specific causes of change are interwoven and complex, but we can identify several broad categories of human activity that due to their sheer intensity and pervasiveness are now driving forces in the alteration of the global ocean.

THE CAUSES OF OCEAN CHANGE

1. Chemical pollution and marine debris

The dumping or discharge of oil, nuclear waste, plastics and other debris, and a vast variety of chemical contaminants causes a wide range of impacts. For example, contaminants directly poison marine life or cause chronic disease, reproductive failure, or deformities. The sources of marine pollution include commercial, military and recreational shipping and boating; run-off from urban streets and agricultural fields; oil drilling installations; and industries and sewage treatment plants.

2. Fishing

Destructive or non-existent fisheries policies and the development of oversized, over-capitalized, over-mechanized and highly subsidized fleets have led to the depletion of numerous fish populations and the collapse of various fisheries. Many commercial fisheries are also responsible for adverse impacts on non-target species and on marine habitats. The incidental catch and mortality of marine mammals, seabirds, sea turtles and unwanted fish species or age-groups by various fishery-types, and the destruction of habitat and benthic communities by bottom-dragging fishing gear, are altering food chains and sea-life communities.

3. Nutrient pollution

The discharge or release of nutrients and other substances - for example, in human wastes in sewage; in fertilizers and animal waste from farm runoff; and in air emissions from coal- and oil-burning electric utilities, industries and gas-burning vehicles - is polluting coastal waters with excess nutrients. Effects include oxygen depletion of near shore waters, promotion of harmful algal blooms, and dramatic reductions in the richness of sea-life communities in affected environments.

4. Coastal development

Urbanization, road construction, port and marina activities, boating, dredging and dumping; mining; and coastal agriculture, forestry, and aquaculture, among other activities, continue to reduce, fragment, or degrade coastal habitats and cause reductions in plant and wildlife populations and local and regional extinctions of species.

5. Exotic species introductions

The introduction of exotic species and their pathogens, often inadvertently, is causing the disruption of natural systems on a global scale. The major cause of marine environment introductions is the transport and subsequent discharge of species via ships' ballast water into environments where they did not previously occur. Other vectors include those aquaculture practices where exotic species are purposefully introduced or can escape into local waters. Introduced or exotic species can prey on or outcompete native species and have caused fundamental and irreversible alterations in natural communities.

6. Damming rivers

The damming or diversion of rivers for power generation, flood control or irrigation purposes has resulted in, among other things, significant reductions and/or changes in the timing of freshwater flow to the sea, reduced sediment flow into deltas and wetlands, and obliteration of fish spawning habitat. Impacts have been widespread and include fisheries reductions, loss of biodiversity, increased concentrations of pollutants, the salinization and subsidence of surrounding coastal lowlands, and the overall alteration of estuaries.

7. Destruction of the ozone layer

The human-induced reduction in the stratospheric ozone layer has allowed increased ultraviolet-B radiation to reach the earth's surface. It has been shown that this radiation can seriously affect human health and damages or kills fish eggs and larvae and tiny planktonic animals and plants which live in the surface waters of the ocean.

8. Global climate change

Human-induced global climate change -- with concomitant sea-level rise, increased air and water temperatures, and changes in precipitation patterns -- is predicted to alter coastal and oceanic environments through a variety of direct and indirect impacts.

SIGNS OF TROUBLE

Although human societies have always altered natural environments, the scale, intensity and speed of such change has increased tremendously in the past century, as a consequence of, among other things, growing populations, higher levels of consumption and increasingly potent technologies (4). Human-induced change in marine and coastal environments is considered by many scientists to already be profound and, yet, the scale of human activity continues to increase. Examples of some of these changes include declines in natural systems and populations, increases in harmful or otherwise negative events such as disease epidemics and algal blooms, and continuing issues associated with environmental pollution:

A. DECLINES IN NATURAL SYSTEMS AND POPULATIONS

1. Declines in seagrass meadows, and in mangroves and other wetlands:

Seagrass ecosystems are vital for fish and invertebrates (including shellfish), mammals (especially manatees), sea turtles, and waterfowl. But they are in decline in most coastal regions of the U.S. (5, 6, 7, 8, 9, 10) -- destroyed by dredging, propeller scouring and disease, poisoned by pesticide and herbicide runoff, and denied sunlight by increased turbidity of the water. Even though seagrasses require nutrients, the excessive input of fertilizer runoff and sewage stimulates masses of algal growth that interfere with seagrass growth. The turbidity of the water, due to blooms of microalgae, is often compounded by increased loads of suspended materials such as sand, silt and clay from activities such as boating, dredging and coastal construction.

Seagrass coverage in the Chesapeake Bay has declined by 90% from historical times (7), while in many estuaries in the northern Gulf of Mexico, the areal extent of seagrass meadows has been reduced by anywhere between 20 and 100% (5). Disease and die-backs continue to plague some seagrass meadows: Florida Bay, for example, has lost over 9,000 acres of turtle grass beds over the past few years (10).

Wetlands along tidal shores have also disappeared at a rapid rate. An estimated 91% of California's original wetlands have been drained or filled in for urbanization and other development activities; Florida's original wetlands (though also including those associated with freshwater) have been reduced by over 9.3 million acres (11). New York State has lost 50-70% of its intertidal shores and mudflats and approximately 98% of its coastal heathland, while 95% of natural barrier island beaches and over 50% of dune habitats have been lost in Maryland (12).

More than half of the original salt marshes and mangrove forests in the U.S. have been destroyed (13). Salt marshes, which are widely distributed along U.S. coasts, are considered one of the earth's most biologically productive ecosystems (14). Mangroves, found predominately in Florida and with some occurrences in coastal Louisiana and Texas, protect shorelines from erosion, buffer the impacts of storms, filter runoff and trap sediments and debris from adjacent uplands, and provide physical habitat and nursery grounds for a wide variety of marine organisms. Mangrove forests in the U.S. are subject to degradation and loss from impounding or ditching for mosquito control, reductions in freshwater input, pollutants, clearing and filling, and diking and flooding (15).

2. Loss of coral reefs:

It has been estimated that at least 10% of the world's coral reefs have been degraded beyond recovery, while a good portion of the remainder is under threat from fisheries, recreational activities, mining and oil exploration, tourism, sedimentation, pollution and disease (16). Turbidity of near-shore waters due to erosion and runoff from logging, agriculture and upland development also contribute to reef degradation. The U.S. National Oceanic and Atmospheric Administration (NOAA) (17) has estimated that over half of all coral reef systems in the U.S., including those in U.S.-affiliated islands such as the Virgin Islands and American Samoa, are at risk and that some systems are virtually dead.

Many reefs throughout the Caribbean are being literally smothered by algal growth, the direct result of the confluence of three factors: intensive overfishing of algae-grazing fish, the catastrophic loss of grazing sea urchins to disease, and nutrient pollution (18). Tracts of reef in Guam have been killed by sedimentation as a result of road construction (19). The potentially lethal black and white band diseases are sweeping through many reefs, and large-scale coral bleaching episodes, in which stressed corals lose (at least temporarily) their symbiotic microalgae, have been increasing since the early 1980s (20). Scientists are accumulating evidence to show that various human impacts have made coral more susceptible to such events (21, 22). Recent monitoring studies in marine protected areas along the Florida coast show that diseases are responsible for significant losses in live coral cover (23).

3. Sharp reductions in fish and shellfish associated with fisheries:

Both commercially valuable and unintentionally captured fish and invertebrates may be the victims of overfishing. In some cases, plummeting fish populations have led to the economic and social collapse of coastal fishing communities with the subsequent loss of thousands of jobs.

A division of NOAA, the National Marine Fisheries Service (NMFS), has jurisdiction over U.S. marine fish and shellfish stocks. In an October 1997 report to Congress, the agency noted that of the 279 fish species where assessment data is available, 86 (31%) are overfished while an additional 10 (4%) are approaching an overfished condition. The status of an additional 448 stocks relative to overfishing is unknown (24).

Historically-abundant fish species in the northeast region, such as cod, haddock, redfish and yellowtail flounder, have been so severely overfished that current levels are the lowest on record. Three stocks of snapper and one of grouper in Hawaiian waters are now at 10-30% of historic levels. Nassau grouper and jewfish in the Caribbean, Gulf of Mexico and the Atlantic have virtually disappeared (25). Though a variety of factors are involved, landings of American oyster in Chesapeake Bay have declined by over 95% since 1980 (26) and, overall, by more than 90% over the last one hundred years (27). White abalone throughout coastal California have been fished to commercial extinction, and their survival is now in jeopardy (28).

In almost every kind of fishery, non-target marine life is also captured. This so-called "by-catch" or "by-kill" makes up approximately one-quarter of the total global fishery catch (29). By-kill from shrimp fisheries may constitute a major problem for some fish populations; for example, in the Gulf of Mexico approximately 500 million spot, one billion sea trout and 7.5 billion croaker are caught and discarded by shrimp trawls every year (30).

4. Extinctions and declining numbers of coastal and marine wildlife:

Though some marine species have been hunted to extinction - for example, the Caribbean monk seal, Steller's sea cow, and great auk (31) - many others have been so seriously reduced that they have ceased to play any ecological role in their environment. There are numerous threatened and endangered species in U.S. coastal and marine environments and include, for example, virtually all of the great whales, six species of sea turtle, the Florida manatee, the Hawaiian monk seal, the roseate tern, Eskimo curlew (a shorebird), Johnson's seagrass, and various fish species and populations (25, 32, 33, 34, 35). Despite localized recovery of some high-profile species such as sea otters, brown pelicans, and elephant seals, overall populations are often far from historical abundances.

Salmon and steelhead in the Columbia River Basin have declined by approximately 90%, and California's winter run Chinook salmon has declined by 99% since 1969. The American Fisheries Society estimates that over 200 distinct races of salmon and steelhead have disappeared and that a further 101 -- out of 211 that are remaining -- are at high risk of extinction (36). The combination of fisheries, coastal development and exploitation has significantly reduced six species of sea turtle, some of which are now critically endangered (37). Harbor porpoise populations along the east coast and from parts of the west coast have been heavily impacted by entanglement in fishing nets (32, 38). The recovery of North Atlantic right whales from historical whaling is likely being prevented by fisheries entanglement and ship strikes (38). Manatees in Florida are similarly being affected by propeller strikes from pleasure boats (39). Black-legged albatross near Hawaii continue to decline from the combination of contaminants and capture in longline fisheries (34).

Change has even occured in more "pristine" areas. In Alaska, various wildlife populations are suffering dramatic, long-term declines. Species involved include harbor seals, Steller sea lions, northern fur seals, and numerous aquatic bird species such as kittiwakes, murres, red-throated loons, and eight species of sea duck including the Steller's and spectacled eiders (40, 41, 42). Depending on the species various causes may or are known to be involved, though much remains conjecture.

B. INCREASE IN HARMFUL OR NEGATIVE EVENTS

1. Harmful algal blooms, and the "cell from hell":

In recent years, there is increasing evidence that "red tides," or blooms, of toxic and harmful marine phytoplankton are increasing in frequency and intensity, and geographic distribution. Some species are being nourished by nutrient pollution, while others are being transported around the globe in ships' ballast water -- to appear, and then thrive, in parts of the world where they were historically absent (43, 44).

Many of these algal species produce virulent toxins which either accumulate in some species, or kill or injure outright. A recently-discovered microscopic "cell from hell", Pfiesteria piscicida, produces a toxin that has killed millions of fish in the estuaries of North Carolina, Maryland and Virginia, and likely in other locations along the U.S. east coast. Humans exposed to the toxin have experienced memory loss, stomach cramps and nausea (45). The emergence of this unique organism as a problem species is believed to have been stimulated, at least in part, by nutrient-rich effluent -- such as from hog farms in North Carolina and chicken farms in Maryland. Pfiesteria is now known to exist along the mid-Atlantic coast as far north as Delaware Bay, and as far south as the Gulf of Mexico (46).

Algal toxins have also killed endangered marine wildlife along U.S. coasts, such as humpback whales off Cape Cod, Florida manatees and monk seals in Hawaii (47). Toxic algae can cause amnesia, paralysis and even death in humans: in 1987, one hitherto unknown poison, domoic acid, killed four people and hospitalized over a hundred in eastern Canada after they ate contaminated shellfish (48). Domoic acid emerged on the U.S. west coast as a human health threat in late 1991 when 12 people were poisoned, though none fatally. Dangerous levels of the toxin were found in razor clams and Dungeness crabs prompting the health departments of California, Oregon and Washington to temporarily shut down the commercial and recreational fisheries for these species (49).

2. Invasion by exotic species and pathogens:

Species and disease organisms continue to be transported via human activities into environments and regions where they did not previously exist. Non-indigenous or "invading" species have caused species extinctions, disease in plants, wildlife and humans, and wholesale changes in the organization of natural environments. The Office of Technological Assessment (OTA) (50) estimated that at least 4,500 species of foreign origin are now established in the U.S. and that their negative economic impact runs from between hundreds of millions to perhaps billions of dollars annually. Though many introductions are inadvertent others occur as the result of the commercial importation of alien species, leading to escapes into the natural environment. The U.S. aquarium industry alone imports more than 2,000 aquatic species from more than 30 countries (51).

Although the most well-known introduced species, such as the gypsy moth, fire ant, zebra mussel or African honey bee, are land- or freshwater-dwelling, marine and coastal environments continue to be invaded by non-indigenous species as well; here, the invaders include seaweeds and phytoplankton, crustaceans, mollusks, polychaetes, and numerous others. Some areas have been particularly impacted. For example, there are at least 150 non-indigenous species in San Francisco Bay, including the Chinese clam, which is now found in densities exceeding 10,000 individuals per square meter (51).

The most common means by which these species are introduced are via the discharge of ships' ballast water and deliberate releases or escapes from aquaculture and aquaria. Every year, an estimated 11,507,000,000 gallons of ballast water is discharged into U.S. coastal environments (51); at least 367 different aquatic plants and animals have been found in the ballast water of ships arriving in Oregon from Japan alone (52).

Of ongoing concern to many island seabird populations is the presence of introduced rats, foxes and other mammals (53); feral and pet cats and dogs can also predate on or disturb mainland seabird colonies. In addition, avian cholera, originally introduced into the wild by the poor waste disposal practices of the poultry industry, now causes major die-offs of birds, including such coastal species as eider ducks (54).

3. Increase and spread of disease events:

A variety of surprising disease occurrences afflicting a wide array of species in U.S. marine environments has emerged over the last 15 years. The following are but a sample of those that have been noticed. An epidemic of fibropapilloma disease, which is characterized by large external tumors, afflicts green turtles in Florida, Hawaii, and the Caribbean, and leatherback turtles in Florida (37). The cause is undetermined.

There have been three recent major disease-related die-offs of bottlenose dolphins -- one along the U.S. east coast and two in the Gulf of Mexico -- apparently due to a canine distemper type of virus (55, 56), though other factors were likely involved. Cancer was found in 65 of 370 California sea lions found stranded along the central California coast (57). New and deadly diseases of coral are being noticed (58) including one afflicting elliptical star coral in the Florida Keys (59). The re-emergence of eelgrass "wasting" disease -- which wiped out great expanses of eelgrass a half century ago -- has been reported along parts of the northeast coast (60). Massive die-offs of east coast fish, notably menhaden, have been attributed to "ulcerative mycosis" which is likely related to the stress induced by an algal toxin (61). And the emergence of "withering syndrome" has had serious impacts on black abalone populations in southern California (62).

C. POLLUTION AND CHEMICAL CONTAMINATION

1. Chemical contamination of fish, seabirds, and marine mammals:

According to the National Research Council (NRC) (63) there are, worldwide, more than 65,000 synthetic chemicals in use, approximately 10,000 of which have regular application. Many of these chemicals accumulate in the tissue of plants and animals that live in contaminated marine waters. An NRC report suggests that adequate information is available to determine risk assessment for only 2% of the chemicals entering the environment. Even less is known of the effects of the complex mixtures of contaminants that are now found within most living organisms (64).

However, many chemicals of human origin found in U.S. coastal waters are known to cause cancer or can disrupt the immune, endocrine and nervous systems in wildlife and humans (65, 66, 67). These effects can occur even when some pollutants, such as dioxins, are present in very low concentrations. Agricultural pesticides are among the most widely and commonly used chemicals; some 30 million pounds are applied to U.S. coastal watersheds annually (68).

Oil, though a naturally occurring substance, is also toxic to marine life. Operational oil discharge from ships, leaks from pipelines and storage tanks, and thousands of small oil spills yearly amount to several billion gallons of oil set free in the environment each year by human activities. Catastrophic oil spills continue to loom as an intermittent threat (69). Activities such as mining and various industrial processes also act to release or concentrate other natural toxic substances, notably heavy metals such as mercury and lead. Coastal waters and bottom sediments have become heavily contaminated in some areas, primarily around ports, industrial outfalls, and various ocean dump sites (70).

Contaminant-related liver cancer has been found in up to 20% of English sole in areas of Puget Sound (71) and in 15% of winter flounder in areas of Boston Harbor (72). Pollutants have been considered the likely cause of a wide range of effects, including stunted or missing dorsal spines, scale disorientation and jaw deformities, in numerous fish species from Biscayne Bay in Florida and elsewhere (73). Studies on bottlenose dolphins in the Gulf of Mexico show evidence that some have compromised immune systems because of such chemicals as PCBs and DDT (74). Even within the vast area of the Pacific Ocean, contaminants have accumulated in upper level predators. For example, dioxins, furans, PCBs, and DDT are considered by scientists to be one important factor in the ongoing decline of the Midway Atoll black-footed albatross (34), a species that spends much of its life over vast expanses of ocean. Synthetic organic pollutants have even been found in deep sea fish off the Atlantic shelf (75).

2. Concentrations of pollutants in the sea-surface microlayer:

Contaminants concentrate in the sea surface microlayer (76, 77, 78), which is an important area for the early development of many fish and other marine species with planktonic life stages (79). Organic molecules concentrate at the water's surface, forming a film held together by the powerful surface tension at the water's uppermost boundary. Some of the many different substances that accumulate in the microlayer are natural and some originate from human-caused contamination of the air and water; but they concentrate in the surface film from anywhere between two to thousands of times more than in the water beneath or the air above (79).

Effects of contaminants on eggs and larvae found at the sea surface in sites along U.S. coasts include mortality, malformation and chromosome abnormalities in fish such as Atlantic mackerel and flounder (80). The hatching success of sole eggs from urbanized areas of Puget Sound was found in one study to be reduced by more than a half (76), while bass embryos collected from the microlayer offshore near Los Angeles had a high incidence of developmental abnormalities and chromosome aberrations (81).

3. Eutrophication:

Large areas of coastal waters have become virtual "dead zones", void of animal life because of the effects of eutrophication. Increased loads of nutrients are washed out from rivers and fall from the atmosphere to over-fertilize coastal waters. This happens primarily as a result of fertilizer runoff from agricultural fields, wastes from livestock operations, discharges from sewage treatment plants, automobile and power plant emissions, and seepage from septic tanks. Stimulated by this rapid influx, microalgae bloom in densities far exceeding the grazing potential of planktonic animals; when the excess algae die they are decomposed by bacteria. However, these bacteria have a very high oxygen demand, so as they multiply, oxygen in the water column and in sediments is depleted. The result is large anoxic (no oxygen) or hypoxic (low-oxygen) areas where fish, invertebrates, seagrasses and other organisms cannot live.

"Dead zones" are not the only negative effect of nutrient pollution. Eutrophication includes many stages between nutrient input and the formation of oxygen-lacking zones. For instance, dense blooms of microalgae promoted by nutrients harm coastal environments by reducing the penetration of sunlight, which reduces desirable submerged vegetation such as seagrasses.

The phenomenon of eutrophication is on the increase worldwide (82). It is common in estuaries polluted by urban and agricultural runoff and has been well documented in the Gulf of Mexico, where the Mississippi flows out (83), and in the Atlantic off the northeast coast of the U.S. (84). The anoxic "dead zone" in the Gulf of Mexico lasts approximately eight months a year and can extend over several million acres (83).

DIFFICULTIES IN ADDRESSING THE PROBLEMS

Presented with such a litany of abuses of the ocean, the temptation is to seek simple answers and swift solutions. Yet, while there are instances in which obvious actions can address specific problems, more often the situation is one that requires a better understanding of the causes of change occurring in marine environments. Lack of knowledge has made it difficult to determine what changes are occurring and when. The complexities of ocean ecosystems and the vagaries of social and political systems combine to frustrate efforts to isolate causes and effects and implement solutions.

1. Mystery

The ocean remains a mystery. More people have walked on the Moon than have visited the ocean floor. Hampered in our ability to see into and study its vast area and depth, our attempts at understanding the ocean are fraught with difficulties. After many years of studying coastal ecosystems, scientists have developed a base of knowledge about the species that live there and how they interact, but for the ocean environment as a whole, much remains speculation. Virtually nothing is known of the vast majority of marine species, their role in ecosystem processes or their relevance to the ocean ecosystem as a whole. Indeed, most marine species have yet to be described (85,86).

It is particularly hard for scientists to accurately quantify the extent and significance of human-induced change, not least because of the paucity of baseline historical data to serve as a comparison between past, pristine conditions and those of the altered present. Long-term records are essential, for example, to distinguish natural cycles and fluctuations from human-induced changes (87).

2. Complexity

The more that we learn about the ocean, the more we appreciate its extraordinary intricacy and complexity. Eons of evolutionary history have produced enormous numbers of networks, interactions and interdependencies, and feedback loops among the oceans' biological, physical and chemical processes, themselves inextricably linked with the overall planetary system. Weather, temperature, winds, tides, currents, chemical cycles and many thousands of marine and coastal species -- including bacteria and viruses, protozoa, reptiles, fish, phytoplankton, seagrasses and seaweeds, coral and other invertebrates, waterfowl, sea turtles and mammals -- are intricately woven together into a globally fluid and dynamic fabric.

As a result of this complexity and of the difficulty inherent in studying and monitoring large "underwater" systems, many puzzles remain unsolved. Scientists are not yet able to explain, for example, the tremendous declines in numerous Alaskan wildlife species. In this case, determining the cause (or causes) is made more difficult because of the confluence of various major changes now recorded in the region, including: a climatic regime shift; toxic chemical pollution; increases in UV-B radiation; and the effects of large-scale fisheries (40,88,89). It is not known whether the red tide that killed over 5% of Florida's manatees in the spring of 1996 was the end result of increased nutrient enrichment from human activity, or solely a natural phenomenon. Likewise, the causes of the mass mortality of turtle grass and other changes in Florida Bay are not precisely known - although many factors, such as high temperatures and salinities, nutrient pollution, reduced freshwater flow from the Everglades, and disease may be involved (90).

The catastrophic mass mortality of bottlenose dolphins along the U.S. east coast in 1987, one of a spate of recent marine mammal mass mortality occurrences worldwide, also exemplifies the difficulties in determining the cause of significant environmental events. The dolphins came ashore in unprecedented numbers and never-before-seen condition, suffering from skin lesions and looking, according to one scientist, as if they had been "dipped in acid" (91). They had succumbed to massive infections, and a wide range of causes were proposed to explain this unique event. Suggestions included algal biotoxins, chemical contaminants, the pathogens associated with sewage sludge dumping, and higher than average water temperature (92), all of which may have weakened the animals. Although definitive evidence was lacking for any of these, analyses of dolphin tissue some seven years after the event revealed yet another possible cause: a highly pathogenic virus (56). Still, numerous questions remain. For example, what prompted the virus to strike when it did? Were the dolphins rendered more susceptible by the high levels of pollutants found in their body, or by algal biotoxins? Or were other, as yet unknown, environmental factors involved?

3. Environmental Surprises

The concept of "surprise" in environmental systems was originally developed by the prestigious ecologist C.S. Holling in the early 1970s. In his words, "surprise" occurs when,

... causes turn out to be sharply different than was conceived, when behaviours are profoundly unexpected, and when action produces a result opposite to that intended - in short, when perceived reality departs quantitatively from expectation. (93)

In other words, "surprise" is a phenomenon that runs counter to our expectations and involves events and conditions that society never imagined could occur (though few surprises are surprising to everyone). Though there are various types of environmental surprises, the overriding concern is that they can involve human tragedy and/or widespread environmental destruction. Indeed, recent history is replete with examples of devastating surprises: Chernobyl and Bhopal; the emergence of such diseases as AIDS, hantavirus infection, Ebola, or Legionnaire's disease; the evolution of antibiotic-resistant bacteria; the biological effects of such chemicals as thalidomide, DDT and PCBs; the destruction of the ozone layer by CFCs; the collapse of the once unbelievably prolific cod stocks of eastern Canada; the massive invasion of zebra mussels throughout the Great Lakes and elsewhere; or the remarkable increase in toxic and harmful algal blooms; among many other examples.

Environmental surprises underscore the complexity of natural systems and the limits of human understanding while demonstrating the potentially devastating environmental responses of human activity and error. Environmental problems, including marine environment change, increasingly reflect the accumulation of human influence over many years. It is now known that these gradual changes, such as the accumulation of CFCs in the stratosphere or of persistent toxic chemicals in the environment, can cause sudden changes in rapid environmental and biological variables that can lead to significant disruption of human health and safety, and of environmental conditions.

The fact that human impacts on natural environments continue to increase has led various scientists to suggest that further serious environmental surprises are likely to occur. Indeed, the Intergovernmental Panel on Climate Change (IPCC) issued the recent warning that a changing climate increases the possibility of "surprises and unanticipated rapid changes" (94).

4. Cumulative Effects

Even when changes are observed, it is not always possible to identify any specific cause, or point to a specific, localized, human activity. This is because, in many cases, changes in marine environments are not the result of any single, large-scale event, but the sum of a series of human activities, of multiple causes exerting effects within a given region.

Although potentially harmful actions individually may not cause concern, they can, when multiplied over time and area, or when combined with other actions, produce dramatic change (95,96).

This is typified by the use of marine pleasure craft in Florida. A study for the Florida Department of Natural Resources notes that there are presently 650,000 registered - and many more unregistered - pleasure boats in the state, and estimates that there will be a total 48% rise in their numbers between 1982 and 2005 (97). Rising numbers of boaters have caused increases in propeller and anchor damage to seagrass beds and coral, greater amounts of marine debris and pollutants, and continued mortality of manatees as a result of propeller strikes. In turn, the construction of docks, marinas and access roads are all components of the cumulative effect of overall development, that have reduced and degraded Florida's coastal marine environment (98).

Indeed, it is the accumulation of dispersed and individually insignificant activities that, in many cases, plays the greatest role in causing progressive change in natural environments. This has been described by an environmental scientist (99) as a result of the "tyranny of small decisions," a scenario in which the environment suffers, "not from a single adverse decision, but from a multitude of small pin pricks."

5. Spatial Scales

Determining the cause or causes or a particular symptom of marine environment change is further complicated by the fact that there is often difficulty in perceiving and monitoring effects that appear far from the source of the environmental disturbance responsible for them (100,101). The impacts, for example, of persistent organic pollutants may occur far removed from the initial discharge location. Ocean and air currents transport substances and organisms, sometimes over very long distances. In this way, the Arctic has become contaminated with high concentrations of persistent organic pollutants, such as PCBs and pesticides, which have originated almost entirely at lower latitudes (102). Migratory and planktonic marine organisms, including planktonic larval stages of non-planktonic animals, swim or drift long distances and may be exposed to a variety of environmental hazards (103). As a consequence, impacts on populations at some intermediate location may seriously affect the population at the end of the migration or drift route.

6. Time Lags

Finally, there is frequently a substantial lag between the time a human activity begins and the manifestation of its impact on the marine environment. Even when environmental change has been identified or predicted, and a contributory cause or causes isolated, there are further time lags before people decide to take action, and still more time before the environment shows any positive response to actions taken.

The story of DDT, a pesticide synthesized in the mid-1940s, is illustrative. It took several years of use before DDT accumulated in the environment at levels that threatened wildlife, and it was not until the 1960s that declining bird populations became evident (104). By the late 1960s, DDT had been identified as the likely primary cause for these declines; and, by the mid-1970s, it had been banned for use in the United States. However, some twenty years after this ban, DDT residues are still found in high levels in wildlife such as dolphins, seals and seabirds, and in humans (105,106). In addition, fifty years after DDT was first synthesized, it is now suspected that it may be causing an increasing incidence of reproductive system abnormalities in human males (107).

Other examples abound: The first official recognition of declining salmon in the Pacific Northwest was issued by the U.S. Fish Commissioner in 1894 (108). The possibility of carbon dioxide-induced climate change was first suggested by Arrenhius in 1896 (109). The naturalist George Perkins Marsh wrote about tropical deforestation in 1874 (110) and R.A. Smith mused on the possibility of lake acidification from industrial emissions in 1872 (111). As is well known, these problems continue.

The vital importance of addressing signs of environmental change at the earliest opportunity is clear. However, the mismatch between time scales of environmental change and the interests of political institutions is particularly acute: where environmental perturbation may require years to accumulate to critical levels, the political process -- already crisis-driven -- is geared almost solely to the short-term and is thus singularly ill-equipped to respond to gradual change in timely fashion.

FUTURE DIRECTIONS

Environmental policies generally require evidence of damage before any appropriate safeguards or changes are implemented. But, as we have seen, the complexity of marine environments, and the limitations of our ability to predict ecosystem responses, mean that providing such evidence is extremely difficult. By the time "proof" is available it may be, at best, extremely expensive or, at worst, too late, to address. Meanwhile, additional problems, requiring additional "proof," continue to pile up. And whereas predictive scientific models are improving, they are not doing so as quickly as humankind's ability to alter the environment.

In a 1993 publication entitled Research to Protect, Restore and Manage the Environment, the National Research Council of the United States (NRC) concluded that:

... if we knew the time to irreversible change in any of the myriad problem areas, we could better assess the degree of urgency that should drive our responses. We do not know those times, however. Too much fundamental understanding is missing - hence the importance of research in critical areas. However, faced with a combination of

potentially very serious consequences but great uncertainty about when or where the troubles will arise, an ounce of prevention is likely to be worth a pound of cure. (112)

Without such prevention, environmental change is likely to become yet more difficult to anticipate or predict, as dramatically-altered systems are less understood than those that have been less disturbed. Unwanted "surprises" are likely to become more and more common. And the likelihood will increase that much of the change to the world's natural systems will prove irreversible, thus further limiting the options for both current society and future generations.

But a continuation of these trends is not inevitable; corrective action can be taken. This paper has provided an overview of some of the symptoms and immediate causes of marine environment change; to begin addressing these, however, will require a great many adjustments, and a long, hard look at a number of underlying principles -- governing issues such as economics, industrial growth, population growth, and material and energy consumption -- that many of us continue to take for granted. Such fundamental change will be difficult. But, in the same way that the fall of the Berlin Wall suddenly ended forty years of a seemingly permanent Cold War, a shift in attitudes and behaviors could rapidly transform the prospects for the ocean and global environment.

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