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Safeguarding the Health of Oceans

ANNE PLATT MCGINN

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Introduction

Prior to the mid-1980s, few people had ever heard of the orange roughy, let alone seen or tasted one. This denizen of deep waters was out of sight and beyond reach for millennia. But with newly improved equipment, fishers could suddenly tap a newfound bonanza. The story of what happened next is emblematic of the far broader challenges facing humanity—and the oceans it depends on—in the 21st century.

Shortly after New Zealand declared its exclusive economic zone (EEZ) in 1978, fishers discovered large numbers of a rarely seen fish called Slimehead along Chatham Rise, an enormous underwater plateau east of Wellington. Almost immediately, fishers rushed to invest in deepwater trawlers, processing equipment, and marketing specialists (who were probably the first to suggest replacing the original name of this "new" fish with something more appetizing). "Orange roughy" appeared in fishmarkets in Europe, North America, and Japan at the same time that Atlantic cod, haddock, and flounder—the world's traditional source of white fish for centuries—were becoming scarce. The mild-tasting, white-fleshed substitute from "Down Under" was an immediate success. Racing to meet demand, fishers sparked a veritable free-for-all almost a mile below the surface, far from shore and beyond the range of sunlight. They perfected saturation fishing, a practice of repeatedly sweeping an area until it is emptied of fish. In 1982, just four years after its discovery, landings of orange roughy averaged 35,000 tons, equivalent to

Early financial support for this project came from the Curtis and Edith Munson Foundation.

U.S. landings of Atlantic cod, a species that has been targeted for centuries. In 1989, fishers hauled away 38,000 tons.[1]

By the late 1980s, researchers had learned that it takes an orange roughy about 30 years to mature and reproduce, roughly 10 times as long as a cod. Using biomass sampling, scientists calculated that the maximum sustainable yield was 7,500 tons. Anything more would drive stocks down. But for eight years in a row, fishers had caught more than five times this level. The New Zealand Fisheries Ministry called for dramatic cutbacks, but their warnings came too late. Just four years after peak harvest in the 1989–90 season, orange roughy catches had plummeted by 70 percent. Now scientists fear the fish will not recover at all.[2]

For much of history, humanity has treated oceans as inexhaustible both in terms of what they could produce and in terms of what they could absorb. Because of the tides that seemed to wash nearly everything away, it looked as though humanity could do no more than temporarily alter the waters closest to shore. That oceans could buckle under the weight of human activities was inconceivable.

Few people have any idea how much we all depend on oceans. People on average obtain 16 percent of their animal protein from fish. And as land-based food supplies hit their own limits, fisheries will become even more vital to food supplies. Two out of three major cities in the world are sited along the coast, and more than 2 billion people live within 100 kilometers of a shoreline. Millions more crowd the world's beaches and coastal areas each year, bringing in billions of dollars in tourism revenues. Oceanfloor deposits are the source of one fourth of the world's annual oil and gas production, and 90 percent of world trade by volume is seaborne. As human populations continue to grow, demands on oceans will intensify.[3]

During the past 100 years, scientists who work among marine fossils both underwater and high in the mountains have traced back the evolutionary roots of life on land to the sea, home to all life on Earth for some 3 billion years. Today, terrestrial life still depends on the sea. Through processes such as evaporation and photosynthesis, oceans and the life they support help regulate the climate, maintain a livable atmosphere, convert solar energy into food, and break down natural wastes. These services are "valued" in the trillions of dollars annually by recent estimates. In reality, though, they are invaluable. Without oceans, life as we know it would cease to exist.[4]

Oblivious to the peril, humanity has pushed the world's oceans close to—and in some cases past—their natural limits. The warning signs are clear. Seven out of 10 commercial fish species are fully or overexploited. Like the orange roughy, many are unable to replenish their stocks. More than half of the world's coastlines are threatened by intensive development, land degradation, and pollution. In 1996, for example, hundreds of American beaches were closed to swimmers because of high rates of bacterial contamination. Known as the rainforests of the sea, coral reefs are critical to fishery production, medicine, and tourism. From the Caribbean to the Indian Ocean, they are dying from cyanide poisoning, pollution-linked diseases, and climate-related stress. In the decades ahead, climate change is projected to pose serious risks not only to marine life but also to the ability of oceans to function properly.[5]

Because oceans are a fluid medium, problems such as pollution affect them differently than they do land masses. Once contaminants enter the sea, currents and tides may carry them far from the original source. Or they may be consumed by a species and move up the food chain, becoming more concentrated as they go. Both pollutants and species continually migrate across boundaries and interact, complicating protection efforts.

Another factor adding to the difficulty of protecting oceans is that many of the existing international institutions working on oceanic issues were created to promote economic growth and development. Early in the 20th century, scientific organizations were formed to study and monitor oceans, primarily with a view to harvesting them. And shortly after World War II, countries extended their national boundaries seaward, seeking to take as much from the sea as could be hauled up. Fishing and shipping groups founded in the 1940s and 1950s looked to develop faster and bigger boats, to gain access to waters further from home, and to convert military technologies perfected during the war to commercial use. Many governments, trade groups, and companies still cling to this frontier mindset today.

Recently, however, policymakers have begun to address some of the urgent problems facing oceans. And the national authorities and international groups that originally focused on promoting development are beginning to move in collaboration with scientific bodies toward wide-reaching efforts on behalf of marine conservation. For each step that is taken in the right direction, though, other efforts founder before they even get to the stage of implementation.

Most oceanic pollution originates on land, but after nearly a decade of political wrangling, international guidelines to address this pollution still have not won the support of national leaders. A global ban on a dozen long-lived synthetic chemicals that threaten oceans is close to becoming reality, but each year, industry introduces hundreds of new ones that quickly become part of marine food chains. In 1995, the governments of most of the major fishing nations approved the text of an international convention that would require countries to cooperatively manage fish that overlap political boundaries. However, several key fishing nations still have not signed the treaty, let alone ratified it. Under enormous political pressure from fishers, governments continue to spend billions of dollars supporting further expansion of the industry, even though fishers already possess more than enough gear and vessels to catch all of the world's available fish.

Although scientists have only begun to understand how fragile oceans are and how essential they are to the balance of life, they stand poised at the edge of an explosion of information and technological advance. Whether this powerful knowledge is bent to the service of the old view of oceans as limitless, or the new awareness of their fragility and importance, is the key question. Given the rapidly deteriorating condition of oceans, humanity has an enormous opportunity to use the new tools and knowledge to make rapid advances in protecting ocean health. The first step is to help people understand the connections between what we do on land and what happens at sea. Only then will governments muster the will to rein in pressures to exploit the seas. But if we continue on the present course of haphazard extraction and disturbance of important parts of oceans, we risk further undermining their health and disrupting the oceans—and ultimately the human economy. The challenge is to use the momentum of recent progress in science, law, and technology to move quickly into a new era of ocean management that protects these irreplaceable resources.

A Planetary Life Support System

From the Mediterranean to the Yellow Sea, human societies have relied on the marine environment for food, commerce, and transportation for millennia. To take advantage of this largesse, ancient civilizations sprang up on coasts of inland seas and oceans where fish were abundant and trade was relatively easy to arrange. In addition to the bounty harvested by humans, oceans also give life in ways that we are only just beginning to understand and appreciate.[6]

Archaeological evidence from the western Pacific reveals that *Homo erectus* began building boats as far back as 800,000 years ago, which suggests that people turned to the sea for food long before fields were plowed for planting. Even before the earliest human settlements, people hunted and gathered shellfish and small fish, supplementing food they collected on land. Fossilized piles of shells along coastal Peru indicate that people harvested shellfish from tidal pools some 12,000 years ago.[7]

Today, fish are the only significant source of the global food supply that people continue to hunt, although on a scale unimaginable even at the turn of this century. In 1997, fishers captured 87 million tons of fish from the sea. On average, people receive about 6 percent of their total protein and 16 percent of their animal protein from fish, as well as critical vitamins and nutrients. For nearly 1 billion people, mostly in Asia, fish supplies 30 percent of protein. Most of these fish come from oceans, although an increasing number are cultured on farms rather than captured in the wild. Aquaculture, based on the traditional Asian practice of raising fish in ponds, has exploded in recent years and now constitutes one of the fastest-growing sectors in world food production.[8]

Marine plants make many conveniences of modern life possible. Entire food, cosmetic, and pharmaceutical industries rely on seaweed and algae for their thickening and gel-forming substances—agar, carageenan, and alginates—which are worth an estimated $400 million per year. While the ancient Phoenicians used seaweed to fertilize their crops, today red and brown algae are used as thickeners in a variety of food products, including salad dressing, peanut butter, ice cream, sherbets, fruit drinks, and cheese, among others. Seaweed derivatives form gel in toothpaste, facial creams, nail polish, emulsifiers, and first aid products; adhesives in glue; and binders in medical capsules and tablets.[9]

In addition to harvesting food and plants from the sea, people have traditionally relied on it for transportation. Metal tools found along Yemen's coastal plain and stone tablets uncovered in Egypt reveal a thriving maritime trade in and around the Mediterranean and Red seas dating back to the Bronze Age, some 5,000 years ago. By harnessing the strong trade winds and seasonal monsoons in the Indian Ocean, Arabs established long-lasting trade routes around 100 B.C.[10]

Far from these early centers of ocean commerce, the hubs of modern-day sea trade are dominated by multinational companies that pay more attention to the rise and fall of stock prices than the tides and winds. Modern fishing trawlers, oil tankers, and container ships follow a path set by electronic beams, satellites, and computers. The volume of seaborne trade increased sixfold between 1955 and 1995. In

1995, ships transported 5 billion tons of bulky cargo, oil, and heavy manufactured goods. By 2020, the volume of all international trade is expected to triple, according to the U.S. National Oceanographic and Atmospheric Administration (NOAA)—and 90 percent of it is expected to move by ocean.[11]

Oceans also offer intangible psychological, aesthetic, and even spiritual values. Many people connect with oceans by watching the sun rise over the water, snorkeling among coral reefs, casting a rod into the surf, or swimming. In the United States, more people visit Miami Beach than Yellowstone National Park every year to enjoy these and other seaside activities. Tourism is also big business. Whale-watching operations generate more than $500 million a year worldwide. In Hong Kong, Singapore, Thailand, Mexico, and Malaysia, coastal tourism generates more revenue than seafood exports. In the Maldives and many Caribbean nations, at least 60 percent of foreign exchange earnings come from tourism.[12]

One subsector of the tourism industry, ocean cruise liners, saw the number of passengers jump 10-fold during the past 20 years. Inspired by this growth, cruise companies plan to invest $10 billion over the next five years to beef up fleet capacity. To accommodate their customers, luxury ships are getting bigger and fancier. Indeed, two recently constructed pleasure ships are too large to fit through the Panama Canal. Today's cruise liners offer everything from casinos, shopping malls, and multiplex entertainment centers, to 24-hour-a-day dining services—in short, everything to make the trip as far removed from nature as possible.[13]

While pleasure boats, tankers, and ships ply the surface waters, cathedral-like oil rigs and elaborate subsea drilling operations mine fuel and mineral deposits below, a development that was virtually unthinkable a century ago. (See Table 1.) Mining for sand, gravel, coral, and minerals (including sulfur and, most recently, petroleum) has taken place in shallow waters and continental shelves for decades. Offshore drilling now supplies a substantial portion of the world's oil and natural gas.[14]

TABLE 1

Ocean-based Industries, by Trends and Value

Industry	Key Trends	1995 Value (estimate)
Coastal Tourism	Tourist arrivals increased more than 20-fold between 1950 and 1995. Expected to nearly double by 2010, especially in Caribbean and Asia-Pacific.	$161 billion
Trade and Seaborne Shipping	Since the 1950s, the annual volume of shipments is up sixfold, to 5 billion tons of oil, dry bulk goods, and other cargo transported in 1995; 27,000 vessels—each larger than 1,000 gross tons—registered. Fifty percent cargo loaded in industrial countries; three fourths unloaded in industrial countries.	$155 billion
Offshore Oil and Gas	First operation in California a century ago; soaring energy demand and better technology prompted take-off after WWII. Today, about 20 percent of the world's oil and natural gas comes from offshore drilling installations in Middle Eastern, U.S., Latin American, and North Sea waters.	$132 billion
Fisheries	Fish production (total capture and culture) up sixfold since 1950—from 20 million tons to 122 million tons in 1997; global per capita supplies up from 8 kilograms in 1950 to 15 kg in 1996. 200 million people rely on fishing for livelihood. Eighty-three percent fish by value imported to industrial countries.	$80 billion

Source: See endnote 14.

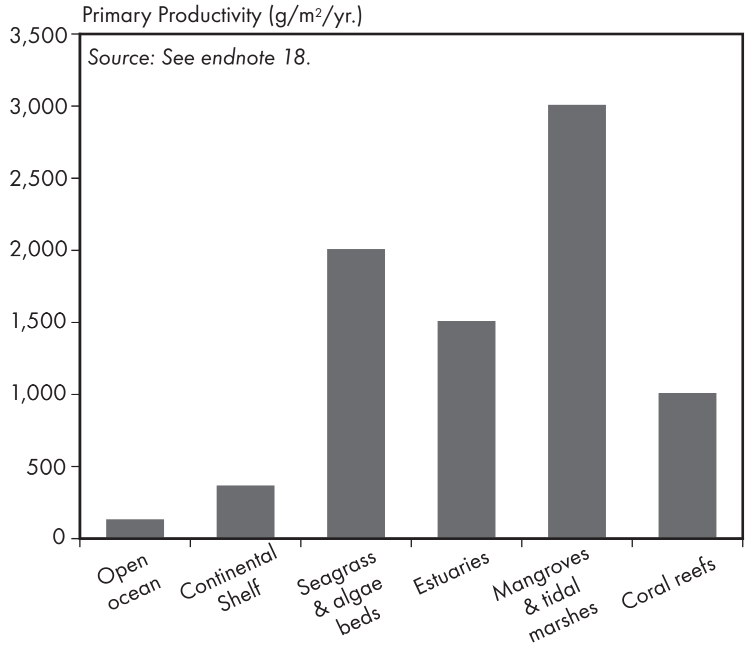
Still undiscovered living resources in oceans are potentially more valuable to human society than petroleum and minerals, for they may offer new forms of life, potential medicines, and genetic material. In 1997, medical researchers stumbled across a new compound in dogfish, *squalamine*, that stops the spread of cancer by cutting off the blood supply to tumors. Marine researchers and bioengineers anticipate many new medical applications will come from the sea in the near future because so little of the marine environment and so few of its inhabitants have been studied. Only 1.5 percent of the deep sea has ever been explored, let alone adequately inventoried.[15]

After hundreds of millions of years' worth of evolution, the oceans today are home to a variety of species that have no descendants on land. Thirty-two out of 33 animal life forms are represented in marine habitats. (Only insects are missing.) Fifteen of these are exclusively marine phyla, including those of comb jellies, peanut worms, and starfish. Five phyla, including that of sponges, live predominantly in saltwater. On an individual basis, marine species count for just 9 percent of the 1.8 million species described for the entire planet. But scientists estimate that as many as 10 million species in the sea have not yet been classified. In 1989, for instance, taxonomists confirmed the presence of a new phylum, the microscopic *Lorcifera*. Discovered by a Danish scientist just six years earlier, these tiny animals live between sand grains on the seabed from 10 to 500 meters below the surface. Marine biologists have only begun to piece together their role in the marine food web.[16]

For centuries, scientists thought the deep sea was completely void of life because it is beyond the realm of sunlight and subject to extraordinarily heavy pressures and extreme temperatures. At an average depth of 3.7 kilometers (about 2 miles), oceans are dominated by abyssal plains that stretch for hundreds of thousands of kilometers along the ocean floor. They are interspersed with canyons that reach down 11 kilometers and other undersea landforms, including vast mid-ocean ridges that form where tectonic plates spread apart. Just in the past 20 years, scientists have discovered life forms that are uniquely adapted to these conditions. In 1978, for instance, scientists discovered hot hydrothermal vents near the Galapagos Islands that had formed where hot methane seeps up from the earth's crust. Previously

FIGURE 1

Net Primary Productivity per Square Meter, by Marine Environment

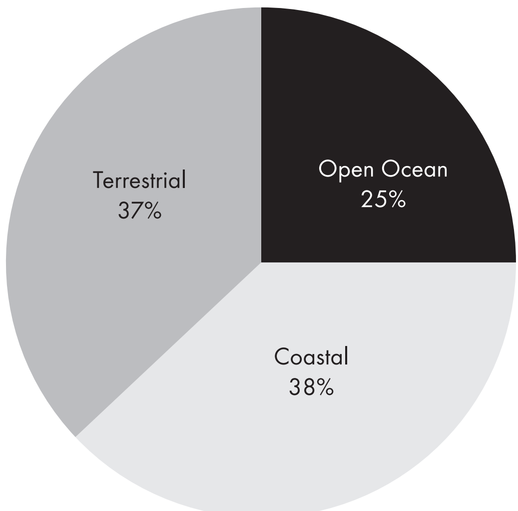


unknown communities of giant clams, tube worms that extend out to 2 meters, and an undetermined variety of microbes make their homes near these vents.[17]

Closer to shore, sunlit waters receive nutrients and sediments from land-based runoff, river deltas, and rainfall, supporting a host of biologically productive areas. (See Figure 1.) Coral reefs, for instance, collectively harbor about 4,000 species of fish. Formed from animals called coral polyps, reefs are among the oldest living communities on the planet. Other coastal communities including mangroves, tidal flats, and kelp forests provide valuable nursery and feeding grounds for a variety of marine species and serve as natural buffers from storms and flooding. Coastal waters are further enriched by cold, nutrient-rich deep-water currents that run

FIGURE 2

Share of Global Ecological Goods and Services, by Environment



Source: See endnote 19.

up against continental margins known as upwelling zones. Worldwide, fishers catch about 90 percent of their commercial landings in coastal areas and on continental shelves.[18]

Within this enormous diversity of species and habitats, the marine environment performs such vital functions as oxygen production, nutrient cycling, water transport, and climate regulation—services that are often taken for granted because they are poorly understood. One recent study estimated that coastal environments account for 38 percent of the goods and services provided by the Earth's ecosystems, while open oceans, which cover 10 times the area of coastal waters, contribute 25 percent. All marine habitats, from those closest to shore to those at the seams of the Earth, are vital to the health of the planet. Together, they produce 70 percent more ecological goods and services than their terrestrial counterparts do. (See Figure 2.)[19]

In a process that has been going on for billions of years, oceans function as a biological pump, continually cycling nutrients between atmosphere and water. Through photosynthesis, tiny marine plants—phytoplankton—take carbon dioxide (CO_2) from the atmosphere and convert it into oxygen and simple sugars, a form of carbon that can be consumed by marine animals. Life evolved on dry land some 245 million years ago when phytoplankton generated enough oxygen in the atmosphere to support species with lungs that could breathe air, rather than gills that filter oxygen from water. The same mechanism continues to feed the marine food chain today. Other types of phytoplankton process nitrogen and sulfur. One group, prymnesiophytes, use sulfur on the order of 20 to 50 million tons a year to produce dimethyl sulphide, which helps seed clouds and may cool the atmosphere.[20]

Sea currents, wind patterns, tidal movements, and temperature gradients render the oceans and atmosphere a coupled system, in which each component responds to pressure and temperature changes in the other. Movement in the upper ocean, for instance, is driven by trade winds that push sea currents away from the equator toward the poles. During the journey to higher latitudes, surface currents release heat to the atmosphere and gradually cool down. Eventually the saltwater becomes cold and dense enough to sink down under warmer, less dense surface waters. As deep water masses reach the poles, they double back under the surface waters, wending along a deep and distant trek around the globe that can take up to 1,000 years. The entire ocean system with its paths and loops is known as the global conveyor belt, for it transports vast quantities of water, species, and dissolved materials far from their source.[21]

The world's oceans also store carbon and help regulate carbon emissions. Although most organic carbon is consumed in the marine food web and eventually returned to the atmosphere via respiration, the unused balance rains down to the deep waters that make up the bulk of the ocean, where it is stored temporarily. Over the course of millions of years, these deposits have accumulated. Today, most of the world's organic carbon, some 15,000 trillion tons, is sequestered in marine sediments, compared with just 4 trillion tons in land-based reserves. On an annual basis, oceans absorb about one third of human-induced carbon emissions from fossil fuel burning and deforestation, or some 2 billion tons, roughly the same amount that land-based resources absorb.[22]

Perhaps no other example so vividly illustrates the connections between the oceans and the atmosphere as El Niño. This event takes place when trade winds and ocean surface currents in the tropical Pacific Ocean reverse direction. Scientists do not know what triggers the shift, but the aftermath is clear: warm surface waters essentially pile up in the eastern Pacific and block deep, cold waters from upwelling, while a low pressure system hovers over South America, collecting heat and moisture that would otherwise be distributed at sea. This produces severe weather in many parts of the world—increased precipitation, heavy flooding, drought, fire, and deep freezes—which in turn has enormous economic consequences. During the 1997–98 El Niño, for example, Argentina lost more than $3 billion in agricultural products due to these ocean-climate reactions, and Peru reported a 90 percent drop in anchovy harvests compared with the previous year.[23]

Whether for fisheries and tourism or life itself, human society relies heavily on healthy and productive oceans. Ocean-based commercial industries are valued in the hundreds of billions of dollars. By comparison, ocean-based ecological goods and services are estimated in the tens of *trillions* of dollars. Quite simply, without healthy oceans, human societies and biological communities will falter. Measuring the ecological value of the planet's life support system is difficult because we have only begun to appreciate how oceans work. And the more we learn about them, the better we understand how human beings are unwittingly undermining their health and integrity.[24]

A Sea of Problems

People cause most of the problems that plague oceans. The ocean's front line of defense—the coastal zone—is crumbling from years of degradation and fragmentation, and its waters have been treated as a waste receptacle for generations. In some places, the loss of buffer areas combined with a rising tide of pollution has essentially suffocated marine life, along with the livelihoods that rely on it. These disturbances have, in turn, given the upper hand to invasive species and climate changes. Although conditions are worst near the coasts, the high seas and polar waters are not isolated from this onslaught: enormous areas are suffering from pollution, and their animal and human inhabitants suffer to an even greater degree than their counterparts in more temperate climes.[25]

The conditions that make coastal areas so productive for fish—proximity to nutrient flows and tidal mixing—also make them especially vulnerable to human assault. Today, nearly 40 percent of the world's population lives within 100 kilometers of a coastline. Although the coast constitutes just 11 percent of total land area of the United States, nearly one third of the country's GDP is produced there, and half of its population calls it home. Population densities in China's 11 coastal provinces average more than 600 people per square kilometer. And in the rapidly growing shoreline city of Shanghai, more than 2,000 people crowd into each square kilometer of land along the sea. This pattern is nearly universal, as two thirds of the world's largest cities are coastal. Many lack adequate sewage and wastewater treatment and continue to dump directly into the water.[26]

In addition to permanent residents, many coastal regions host an annual pilgrimage of pleasure-seekers and sun worshippers with some fairly predictable effects. Each year, the population along the Mediterranean coastline explodes, adding more than 100 million visitors to the region's 160 million year-round residents. Because they concentrate in some of the region's most fragile areas and lack a sense of local stewardship, these tourists contribute substantially to the degradation of dune systems, persistent drinking water shortages, and the near extinction of monk seals and sea turtles. In tropical Pacific nations, rapidly growing tourism has generated a wave of resorts, hotels, and golf courses that contribute specific problems to already beleaguered seaside habitats. Construction-related sediments, fertilizers applied to hotel grounds and golf courses to keep them looking pristine green, and a flood of phosphate-containing detergents used in laundry facilities compound the pressures on the marine environment.[27]

The conditions that make coastal areas so productive also make them vulnerable to human assault.

With more people moving to, living in, and visiting coastal areas, it is not surprising that these valuable ecosystems are losing ground. During the last 10 years, for instance, Korean developers have filled in about 40,000 hectares of wetlands in Kyunggi Province to create new land for coastal development. Researchers at the Korean Maritime Institute estimate that these wetlands used to provide about $1 billion in fisheries and recreational benefits. Since the early 20th century, nearly half of the coastal wetlands in the world have been filled in or severely degraded.[28]

Filling in wetlands and thereby losing natural buffer zones costs home and business owners millions of dollars in property losses when shorelines are pounded by storms and floods. In the United States, for instance, insured coastal property damage climbed to $50 billion in the 1990s. The coastal barriers, seawalls, jetties, and levies that are designed to protect human settlements from storm surges likely exacerbate the problem of coastal erosion and instability, as they create deeper inshore troughs that boost wave intensity.[29]

In addition to storm protection, society also loses potential food. People in just four countries—Malaysia, the Philippines, Thailand, and Viet Nam—have cleared 750,000 hectares of mangroves, an estimated 10 percent of all remaining mangrove forests in South and Southeast Asia.

Many were cut down to grow shrimp that farmers could then sell for export. An analysis conducted in the Philippines shows that one hectare of mangrove forest can sustainably produce 380 kilograms of fish, and provide nursery grounds for an additional 475 kilograms of fish and shrimp that mature elsewhere each year, in addition to storm protection and water regulation benefits. Assuming a sustainable production rate of 850 kilograms per hectare, these mangroves annually produced and nurtured 6.4 million tons of fish and larvae—enough to feed 25 million people at a level of 25 kilograms per person. In contrast, their replacements—high-density, intensive shrimp ponds—produce between 1 and 3 tons of shrimp per hectare for about five years, at which point the pond is abandoned completely because it so choked with wastes that is unable to support life of any kind.[30]

Between 1983 and 1994, more than 90,000 hectares of seagrasses were destroyed in temperate areas. According to a study conducted in Puget Sound, Washington, one hectare of eelgrass generates about $400,000 in nutrient cycling benefits for the marine food web. Assuming a more conservative estimate of $100,000 per hectare, this global loss of seagrasses represents about $9 billion in lost ecological value.[31]

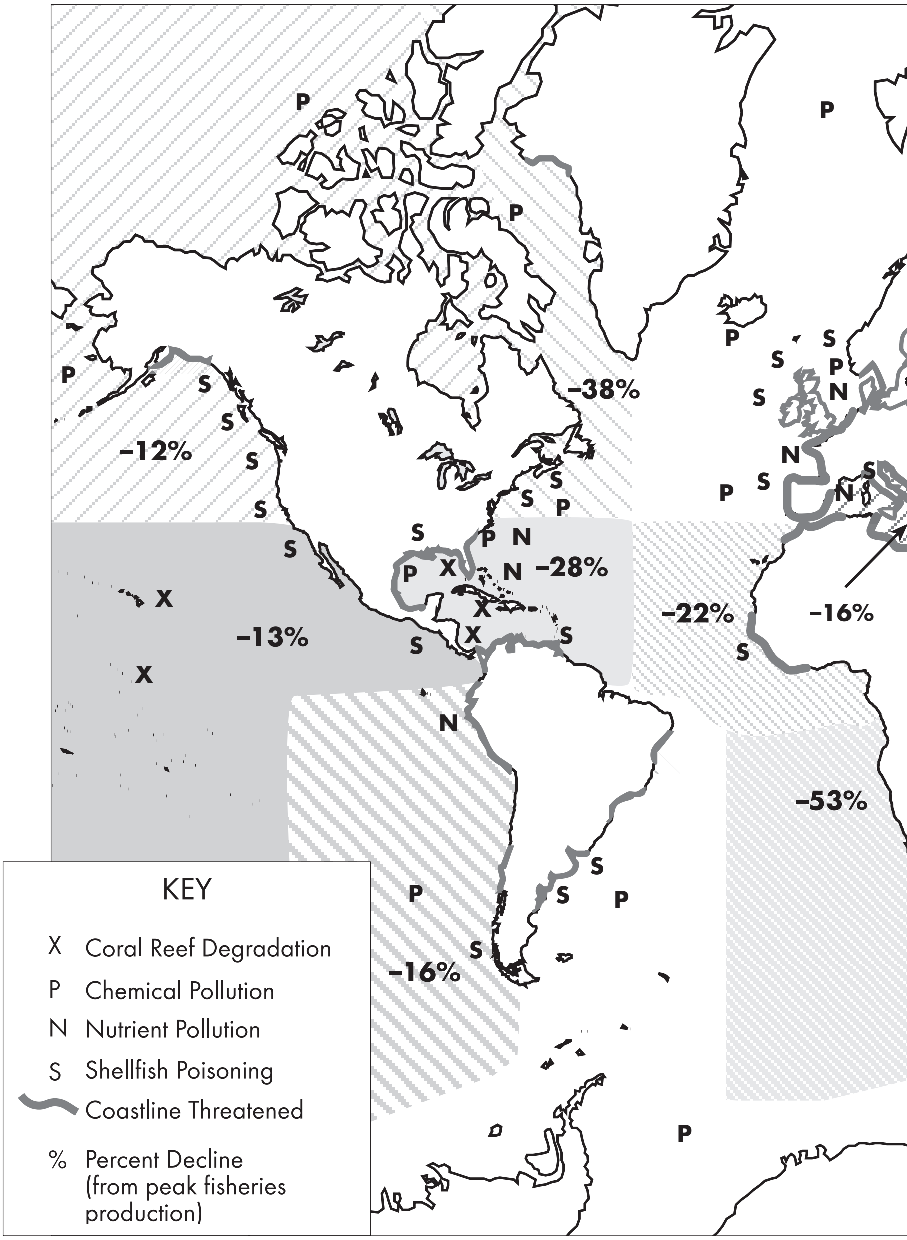
In addition to converting seashore areas to urban developments, golf courses, and shrimp farms, human activities on land also cause a large portion of offshore contamination. An estimated 44 percent of marine pollution comes from land-based pathways, flowing down rivers into tidal estuaries, where it bleeds out to sea. An additional 33 percent is airborne pollution carried by winds and deposited far offshore. From nutrient-rich sediments, fertilizers, and human waste to toxic heavy metals and synthetic chemicals, the outfall from human society ends up circulating in oceans, often for extended periods of time. Once contaminants collect in zooplankton, larvae, and small fish (often by direct consumption), they work their way up the food chain and cause problems in the fish, marine mammals, and people who eat them. (See Figure 3.) [32]

Among the most visible signs of the pollution problem are out-of-control blooms of algae that blanket coastal areas. Since 1986, China's State Oceanographic Administration has reported five major episodes of uncontrolled algal blooms (with two in 1998), each affecting more than 500 square kilometers. Although they are a naturally occurring phenomenon, the frequency and severity of harmful algal blooms (HABs) has increased in the past three decades, as has the appearance of novel toxic species. (See Figure 4.) Between 1970 and 1990, for instance, the incidence of paralytic shellfish poisoning doubled worldwide as the plankton carrying the toxin spread from the northern to the southern hemisphere. More than 60 harmful algal toxins are known today, compared with just 22 in 1984.[33]

Some algae become harmful by virtue of their biomass. Growing to nearly a million cells per milliliter of seawater, algal blooms covering broad areas of surface water can block sunlight and air from reaching the life below. The problems become worse when the algae die: they sink to bottom waters where bacteria digest them, consuming more oxygen in the process. Eventually, the bacteria-laden waters become so depleted of oxygen (a condition known as hypoxia) that they suffocate marine animals, which either flee or die. In the Gulf of Mexico, this process has rendered nearly 16,000 square kilometers of water biologically dead. During the warm summer months, large portions of the Adriatic, Baltic, and Black seas suffer from hypoxia, prompting swimming bans, beach closures, loss of tourism revenue, and massive fish kills.[34]

Other algae can cause problems in small doses because they carry toxins. In fish, neurotoxins are absorbed through the gills, often asphyxiating them within a short period of time. Many toxins are fat soluble and collect in the fat tissue of fish and shellfish. Among the human diseases connected with HABs are paralytic, diarrhetic, and neurotoxic shellfish poisoning and ciguatera fish poisoning. The latter afflicts 10,000–50,000 people each year. Ailments in people can progress from diarrhea, vomiting, and other flu-like symptoms to dizziness, paralysis, or even death. Ciguatera is par-

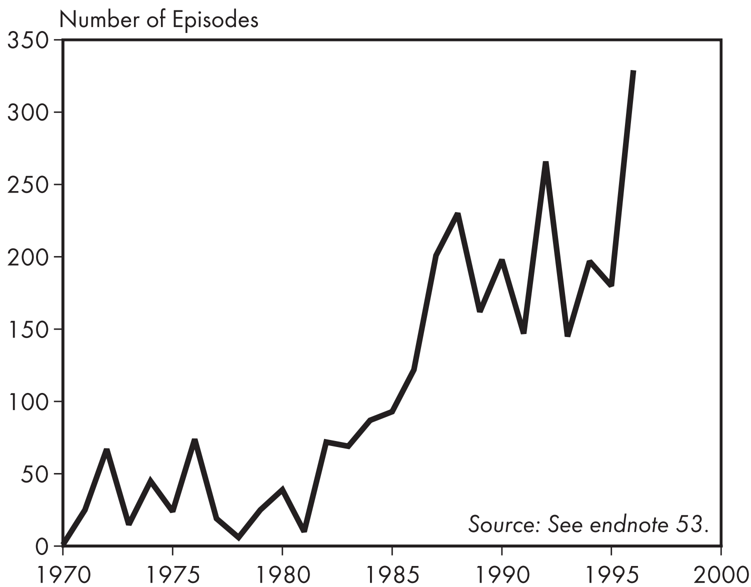
FIGURE 3
Global Marine Hotspots and Declining Fisheries



Source: See endnote 32.

FIGURE 4

Harmful Algal Blooms in the West Central Atlantic, 1970–96



ticularly common in the tropics because more than 400 different species of fish can carry it, including ones that people eat, including grouper, snapper, and mackerel.[35]

Many harmful algal blooms are linked to increasing quantities of nitrogen and phosphorus in coastal areas, largely from nutrient-rich wastewater and agricultural runoff. These two nutrients are necessary for life, and in proper quantities they help plants grow faster. But in areas with limited water flows, the waters can suffer from overenrichment (eutrophication), which triggers the oxygen depletion that leads to algal blooms. Between 1976 and 1986, for example, the population of Tolo Harbor, Hong Kong, increased sixfold, while phosphate inputs rose threefold, and the incidence of HABs jumped eightfold.[36]

Not all outbreaks can be traced to altered water chemistry; habitat alteration and climate change are also thought to play a role. Ciguatera poisoning, for example, tends to flare up in the wake of careless tourists, hurricanes, and El Niño, all of which can disturb coral reefs and allow dangerous algae to expand their range, thus increasing the chances that fish will eat them. In Borneo, Papua New Guinea, and the Philippines, human cases of paralytic shellfish poisoning rise during El Niño years because the warmer waters favor the growth of algae and their toxins.[37]

As the harmful blooms spread, so do the associated problems. In late spring 1997, more than 100 endangered Mediterranean monk seals—one third of the world's population—were found dead along the West African coast, a die-off researchers have linked to algal toxins. In September of that year, a red tide outbreak in Kerala, India, forced authorities to shut down shellfish beds and ban sales, leaving nearly 1,000 families without work. About six months later, harmful algae wiped out more than $10 million worth of high-value fish in Hong Kong's mariculture industry. Since 1991, harmful algal blooms in the United States have caused nearly $300 million in economic losses in the form of fish kills, public health problems, and lost tourism and seafood revenues.[38]

Some toxins and diseases have emerged that are new to science. In 1991, for example, thousands of menhaden suddenly went belly-up in the Pamlico and Albemarle sounds in North Carolina, the second largest nursery area for marine fish on the U.S. Atlantic seaboard. A toxic phytoplankton, *Pfiesteria piscicida*, was identified as the cause, but so far it has eluded efforts to contain it. *Pfiesteria* has at least 24 life stages and hibernates in bottom sediments as a non-toxic cyst until the conditions are right to emerge in attack mode. It has since been identified in other estuaries along the eastern U.S., including Maryland and Virginia. In 1997, an outbreak occurred in three tributaries to the Chesapeake Bay, killing 30,000 fish and sickening more than two dozen people. (The human health effects range from respiratory problems to memory loss and learning impairment.) Sales of world famous Chesapeake crabs, oysters, and fish plummeted in response.[39]

Unlike red tides, which historical records suggest date back to Biblical times, synthetic chemicals are a fairly recent addition to the marine environment. But they, too, are proving to have pernicious effects. First manufactured in the 1930s, synthetic organic compounds such as chlordane, DDT, and PCBs are used for everything from electrical wiring to pesticides. Indeed, one reason they are so difficult to control is their ubiquity. The organic form of tin (tributyltin), for example, is used in most of the world's marine paints to keep barnacles, seaweed, and other organisms from clinging to ships. This substance can impair their immune and endocrine systems once it is dissolved in water and ingested. Stocks of marine snails in harbors throughout the world have declined because of organotin paints. Similarly, scientists suspect that a recent sea otter die-off in California was caused by several milligrams of tributyltin that concentrated in their livers. Apparently, this was just enough to damage the animals' immunity so that a normally harmless infection became fatal. North Sea waters receive about 68 tons of this substance every year.[40]

As part of a larger group of chemicals known collectively as persistent organic pollutants (POPs), synthetic chemicals are difficult to control because they do not degrade easily. Highly volatile in warm temperatures, organic pollutants tend to circulate toward colder environments such as the Arctic Circle where the conditions are more stable. Moreover, synthetic chemicals do not dissolve in water, but are lipid-soluble, which means that they accumulate in the fat tissues of fish that are then consumed by predators at a more concentrated level. Thus scientists have found accumulations of 100 to 1,000 times the input level in species at the top of the food chain—from seabirds and seals to polar bears and people. Whether they are transported directly by air and water, carried from species to species through the food chain, or passed on from generation to generation through reproduction, persistent organic pollutants have been implicated in a wide range of animal and human health problems—from suppression of immune systems, which leads to higher risk of illness and infection, to disruption of the endocrine system, which can eventually cause birth defects and infertility.[41]

Given the extended lifetimes of persistent organic pollutants and their relatively recent introduction to the cast of chemical pollutants, experts expect to find increasing signs of their infiltration into the marine food web and accumulation in marine species over time. Between 1969 and 1992, monitoring showed a steady increase in DDT concentrations in Arctic polar bears. A recent survey on Baffin Island, Canada, of Inuit people who consume large quantities of walrus and seal meat and blubber found blood levels of toxaphene and chlordane 20 times higher than what the World Health Organization estimates is safe. These two insecticides have been banned in the United States for more than 15 years. Continued and widespread use of organic chemicals in any part of the world can pose a serious threat to marine life and fish consumers everywhere, particularly in polar regions.[42]

Experts expect to find increasing signs of chemical infiltration into the marine food web over time.

Heavy-metal contamination is another lasting legacy of the industrial age. And like persistent organic pollutants, metals also bioaccumulate in marine species. Since 1886, marine concentrations of methylmercury have increased threefold in the mid-latitudes of the North Atlantic, rising at about 1.3 percent annually. In the Baltic Sea, concentrations of mercury have grown fivefold during the last 50 years, largely due to the air deposition resulting from fossil fuel burning. Many fish in the Baltic are blacklisted because they contain too much mercury for safe human consumption. A similar trend has occurred in the North American Great Lakes.[43]

Not all marine pollution originates on land. Nearly one fourth comes from shipping and other offshore activities. Despite international bans, ships discharge between 5 and 50 million tons of oil at sea each year. Annually, more than 700,000 tons of crude oil are spilled into the Mediterranean. Chronic oil pollution and spills are estimated at 25 million barrels of oil a year, much of it killing seabirds and animals. By the year 2010, shipping is expected to contribute one third of sulfur emissions in Europe.[44]

Although oil spills receive greater public attention than routine runoff and non-point pollution, measuring their ecological effects is no less difficult. A recent study of 1,776 shipping accidents involving oil and chemicals showed that only 54 percent of the reports contained some type of information about the environmental consequences of the spill. Moreover, only 10 percent of the reports had information describing the impact on ecosystems, and only 2 percent reported any effect on living organisms.[45]

Already weakened by a combination of habitat degradation and pollution from agriculture and industries, heavily stressed marine and coastal environments are more susceptible to invasive species than they used to be. Globally, several thousand species are estimated to be in ships' ballast tanks at any given time. U.S. waters are thought to receive at least 56 million tons of discharged ballast water a year. The combination of ships in motion and regular flushing means that species get a free one-way ticket to a foreign destination. In San Francisco Bay, for instance, researchers catalogued 234 exotic species and concluded that one foreign species takes hold in the bay every 14 weeks, often through ships' ballast water. The Atlantic comb jelly was probably released into the Black Sea from a ship's ballast water about 1982. With no natural enemies in the Azov and Black seas, and a taste for fish eggs, larvae, and other zooplankton, the jellyfish has since decimated life in the region. Cumulative losses to Black Sea fisheries are estimated at $350 million. Based on sampling in these and other areas, researchers identify marine bioinvasions as "a major global environmental and economic problem."[46]

Marine species are highly sensitive to changes in temperature and environmental conditions. Recent evidence shows, for example, that the thinning ozone layer above Antarctica has allowed more ultraviolet-B (UV-B) radiation to penetrate the waters, reducing photosynthesis and the growth of phytoplankton and macroalgae. But the effects are not limited to the base of the food chain. Increased intensity of UV-B radiation damages the larval development of crabs, shrimp, and some fish. By striking aquatic species during their most vulnerable stages of life and reducing their food supply at the same time, increases in UV-B could have devastating impacts on world fisheries production.[47]

Climate change also poses grave risks for marine species. Warmer waters can alter migration and feeding patterns of saltwater species by forcing them to higher latitudes or deeper down in search of food. Elevated temperatures can also impair animals' immune systems while favoring the growth of pathogens and toxic phytoplankton. Illness can further depress sea creatures' ability to breathe and eat, often leaving them stranded in unusually warm or cold waters. From November 1997 to February 1998, the first four months of the most recent El Niño, 25 major marine mammal strandings and die-offs were reported in the popular press worldwide. In several cases, the mammals died in areas where they had never been seen before.[48]

When corals are subjected to any number of stresses, such as warmer water or lower-than-normal tides, they expel symbiotic zooxanthellae (tiny plants). This change gives them a bright white, or bleached, look and means that the corals cannot grow or reproduce. First spotted in the mid-1980s, coral bleaching has since been reported regularly throughout the Pacific and Caribbean. In spring 1998, marine scientists confirmed that the bleaching stretched throughout the tropics, including, for the first time, the Indian Ocean from the Maldives to the Northern Andaman Islands. Scientists have linked the latest bleaching events to an increase in sea surface temperature of 1° Celsius due to El Niño, although other instances are related to a complex mix of monsoonal, oceanographic, and climatic variables. As with other marine species, corals that have been subjected to extreme conditions such as bleaching also become more vulnerable to infections. In the Caribbean, *Aspergillus*, a fungus normally limited to crops on land, has recently killed sea fans, a type of soft coral.[49]

Because higher temperatures cause water to expand, thus giving it more energy, a warming world may trigger more frequent and damaging storms. In 1995, scientists recorded the highest sea surface temperature in the north Atlantic Ocean ever, the same year the region was hit with 19 tropical storms—twice the previous 49-year average.[50]

Depending on the rate and extent of warming, global sea levels may rise 5–95 centimeters by 2100—up to five times as much as during the last century. The effects of this shoreline migration would be dramatic: a 1-meter rise would flood most of New York City, including the entire subway system and all three major airports. Economic losses could cost the global economy up to $970 billion in 2100, according to the Organisation for Economic Co-operation and Development. Of course, the human costs would be unimaginable, especially in the low-lying, densely populated river deltas of Bangladesh, China, Egypt, and Nigeria.[51]

This damage could be just the tip of the iceberg. Warmer temperatures will likely accelerate polar ice cap melting and could boost this rising wave by several meters. Just four years after a large portion of Antarctica broke off, another large ice sheet fell into the Southern Sea in February 1998, rekindling fears that global warming could ignite a massive thaw that would flood coastal areas worldwide. Because oceans play such a vital role in regulating the Earth's climate and maintaining a healthy planet, human-induced climate change could have serious repercussions for oceans and trigger complex chain reactions that scientists have yet to understand. One recent study suggested that hurricanes may cause a short-term decline in oceanic absorption of carbon dioxide.[52]

Understanding the links between climate and oceans is just one of many interrelated ocean issues that demand more attention from scientists and more action from the public. We have drastically altered the marine food web and inshore habitat areas. Some coastal areas are already biologically dead and some marine wildlife are already poisoned. These trends will prove irreversible if we continue on our present course of urbanization, coastal development, and pollution. Nowhere are the cumulative effects of human actions on marine ecosystems clearer than with respect to fishing.

Hitting the Limits of the Sea

The health of marine fisheries is an important indicator of the health of the oceans. At first glance, all appears well. In 1997, world fish production—wild catches and farmed fish combined—reached 122 million tons, up sixfold from 1950. Fish is still an affordable choice at most restaurants and supermarkets. But beneath the surface, things are not so bright. Years of relentless exploitation in the oceans have taken their toll: 11 of the world's 15 most important fishing areas, and 70 percent of the major fish species, are either fully or overexploited, according to the U.N. Food and Agriculture Organization (FAO). (See Figure 3.) Landings of the most commercially valuable species, including cod, tuna, and haddock, have dropped by one fourth since 1970.[53]

Consumer demand in industrial countries for high-end specialty products such as the eggs of endangered sea turtles, shark fins, live reef fish, and farmed shrimp provokes extreme practices taken without heed for ecological or human costs—poisonous fishing methods and life-threatening smuggling, for example. It also fuels the growing transfer of protein from South to North: 83 percent of fish by value are exported to industrial countries each year. Such practices push marine resources further toward collapse, undermine legitimate attempts to improve fisheries management, and work against the growing need for food security. In addition to the people already suffering from malnutrition, more than 1 billion poor consumers who depend on fish to fulfill their protein needs may become malnourished if per capita fish supplies fail to keep pace with growing human appetites.[54]

One reason marine exploitation is not readily apparent is that farmed fish (aquaculture) is filling in the gap created by depleted wild stocks. Aquaculture production has grown steadily in the last 13 years—from 7 million tons of fish in 1984 to 28 million tons in 1997. Used primarily for direct human consumption, these new supplies mask sharp declines in most of the world's valuable fish stocks.[55]

Another factor masking the decline of ocean fish stocks is that fishers are taking smaller fish that tend to reproduce at a younger age, and are generally less commercially valuable. During the 1980s, for instance, five low-value open-sea species—the Peruvian anchovy, South American pilchard, Japanese pilchard, Chilean jack mackerel, and Alaskan pollock—accounted for 73 percent of the increase in world landings. But unless the volume of fishing is reduced, the cycle of overfishing will soon repeat itself with new prey. Excessive fishing can trigger abrupt declines in these lower-level species, leaving fishers only steps away from the base of the food chain and economic and ecological disaster.[56]

Overfishing poses a serious biological threat to ocean health because of the scale of activity—fishers possess at least twice the capacity they need to catch all the available fish—and the thoroughness with which it is conducted. Capturing fish faster than they can reproduce reduces the size and genetic diversity of the spawning stock, making it more difficult for the species to adapt to future environmental changes. Species such as the orange roughy, for instance, may have been fished down to the point where future recoveries are impossible.[57]

Depleting fisheries can send shockwaves through the marine food chain. In Alaska, for example, pollock catches have nearly tripled since 1986. Since the late 1960s, populations of Steller sea lions, which feed on pollock, have dropped 80–90 percent in the Gulf of Alaska. In 1990, the National Marine Fisheries Service (NMFS) designated the sea lion as threatened under the Endangered Species Act. And in May 1997, the species was reclassified as endangered. In turn, the loss of sea lions has deprived killer whales of their primary source of food. The whales are now eating sea otters, a leaner and bonier mammal than sea lions. As a result, sea otter populations have declined by 90 percent since 1990, triggering a surge in their prey, sea urchins.[58]

In the process of removing 87 million tons of fish from the sea every year, fishers harm many innocent bystanders. Large quantities of fish and marine animals known as bycatch are wasted annually, thrown out because they are undersized or nonmarketable, or because a fisher does not have a permit to catch them. FAO estimates that discards of fish alone—not counting marine mammals, seabirds, and turtles—total 20 million tons, equivalent to nearly one fourth of the annual marine catch. Many of these fish do not survive the process of getting entangled in gear, being brought onboard, and then tossed back to sea. The losses are particularly striking in shrimp fisheries. Working with fine-mesh nets and in areas of high species diversity, shrimp trawlers on average net 5 kilograms of unwanted species for every kilogram of shrimp they keep.[59]

Careless fishing practices also damage the areas that fish rely on for their most vulnerable stages of life—breeding, spawning, and maturation. Tropical coral reefs of Southeast Asia bear the scars from fishers who squirt sodium cyanide poison at fish to stun them, making it easier to trap them alive. Live fish can earn fishers 400–800 percent more income than the same species dead. Almost unheard of 15 years ago, the use of cyanide poison is now suspected in reef fisheries from Papua New Guinea to Tanzania. Though the amount of poison is too little to harm people who later eat the fish, over time this practice can kill most reef organisms and convert a productive community into a graveyard.[60]

Another threat to habitat areas stems from trawling, the process in which nets and chains are dragged across vast areas of mud, rocks, gravel, and sand, essentially sweeping—in some cases, mining—everything in the vicinity. Now considered a major cause of seabed degradation, trawling disturbs bottom-dwelling species and structures. By recent estimates, fishers trawl all the ocean's continental shelves at least once every two years, with some areas hit several times a season. Trawling affects an area 150 times greater than the

TABLE 2

Marine Species on the IUCN *Red List* and the CITES Appendices

	Red List	CITES Appendix I[1]	CITES Appendix II[2]
Whales, dolphins	13	22	All cetaceans
Marine otters	1	1	1
Seals, sea lions	12	3	9
Sirenians	3	3	1
Birds	61	4	1
Reptiles (sea turtles)	9	7	1
Fish	111	2	
Mollusks	10		10
Coral	2		All stony and black corals

[1]Risk of extinction; international trade prohibited.

[2]Vulnerable to exploitation but not yet at risk of extinction; international trade in permitted manner.

Source: See endnote 62.

global area of forest that is clearcut each year.[61]

As a result of careless practices, climate change, and other threats, several large marine predators, including dolphins, whales, seals, and tuna, have been depleted beyond the point of commercial extinction to biological danger. Heir to an ancient lineage of vertebrates dating back some 400 million years, sharks are at their lowest point of all time. (Their longevity and low rates of reproduction make them especially vulnerable to overexploitation.) Five percent of the species on the World Conservation Union's (IUCN) *Red List of Threatened Animals* are now marine, including several whales, seals, and turtles. Considering how few marine species have even been described, let alone adequately assessed for population status and distribution, more could soon join the list. (See Table 2.) Researchers fear that the barndoor skate may bypass the list altogether by becoming the first marine vertebrate to go extinct. Caught as bycatch in trawl nets, populations of these large, noncommercial species are quickly fading away in the Northwest Atlantic.[62]

As the fish disappear, so too do coastal communities. The fate of more than 200 million people around the world who depend on fishing for their income, food security, and way of life is also uncertain. Out-of-work fishers, ship workers, and vessel owners are growing in numbers, especially in Canada and Europe. While intended to tide the industry over until more prosperous times, emergency funding and government subsidies bolster an already bloated global fishing fleet. Subsistence and small-scale fishers in developing and industrial countries, who catch nearly half of the world's fish, suffer the greatest losses because they cannot compete with large-scale vessels or changing technology.[63]

Conflicts like the 1995 gunboat stand-off between Canada and Spain are more common than before. In that case, Canadian patrols boarded two Spanish vessels that were moving in and out of Canadian waters, looking for fish. In the South China Sea, reports of pirate gangs hijacking fishing boats, and even tankers on occasion, have increased as the traditional superpowers, the United States and Russia, have reduced their naval presence there. Nearly half of the world's 225 shipboard attacks reported in 1997 occurred in this region.[64]

With tensions over fisheries increasing, demand for fish rising, and local food security at risk, the stakes are higher today than ever before. Accelerating economic and social desperation continues to drive fishers down the path of self-destruction, threatening to decimate world fishery resources. Overcoming this legacy of mismanagement will not be easy. The extent to which fisheries can recover depends on how quickly and to what degree redundant fishing fleets are retired; how soon fishers stop pulling in fish that are too young, too small, or too scarce; and whether fishers reduce waste, limit environmental damage inflicted in the process of fishing, and make better use of what is caught. If the industry is to survive, fisheries management will need to make a fundamental shift away from managing fish supplies to managing the fishers and how they fish.

Bridging the Knowledge Gap

The first global oceanic scientific expedition was conducted by British scientists who enlisted a naval warship for the task. Between 1872 and 1876, the *HMS Challenger* sampled waters from every sea. With steel cables and thousands of glass jars, the crew hauled in a bounty never seen before by human eyes. They discovered more than 4,000 species that were entirely new to science. The expedition was considered such a milestone in scientific discoveries that the ship's name was given to NASA's first space shuttle in 1981.[65]

Our understanding of marine species and systems, while certainly more advanced than in the days of the *HMS Challenger,* is still, at the dawn of the 21st century, surprisingly elementary. Scientific understanding of oceans lags decades behind our knowledge base of terrestrial systems. In part, this is because oceans are inherently difficult to study. The medium is never still, and scientific experiments more than a few meters down are extremely expensive.[66]

In the 1960s, U.S. scientific advisors argued that we knew more about the backside of the moon than about the oceans. That unfortunate state of affairs continues today: for every $1 dedicated to funding NOAA, more than $6 are allotted to NASA's space research and operating budget. Moreover, federal funding in the United States for ocean-related research has dropped by half since 1982, relative to funding in other sectors. Perhaps more telling in terms of how oceans rank is the fact that the U.N. General Assembly, which reports on progress and developments in the international Law of the Sea, dedicates just one day a year to oceanic issues.[67]

The short shrift given to the oceans may change in the near future. A 1998 U.S. National Research Council report concludes that ocean sciences are on the verge of critical breakthroughs. Technology and ocean sciences have advanced to the degree that exponential progress and ground-breaking developments can be expected in the coming decades. With computerized models, more data can be collected in one hour than the *Challenger* collected in five years. Although predicting the exact course of ripple effects from pollution and climate change may be impossible, with the help of new technology, scientists can better anticipate the occurrence of algal blooms, for instance, and track their effects.[68]

But the very tools that will build stronger foundations for ocean knowledge also create risks and side-effects that could dramatically alter the whole system. The danger is that scientists and commercial developers who stand poised to tap into ocean resources that have evolved over several thousand millennia will proceed without ensuring environmental protection *before* operations begin. To date, the technology that has made it possible to understand the ocean has been used to accelerate its destruction. Satellite systems have been used to find fish faster and in deeper waters. Remotely operated vehicles have opened the way for companies to exploit the enzymes and proteins of deepwater species even before scientists understand their role in the ecosystem. However, if technology is carefully applied, it offers tools that will not only help people become aware of the oceans' vast potential and the enormity of the threats to them, but can actually help reverse their decline.[69]

Studying and understanding something as vast as the oceans requires many tools and perspectives, from satellite technology to human observation. Each has a valuable role to play in advancing our knowledge and appreciation. For instance, remote sensing devices have been used to track the impact of tropical cyclones on reefs in the Cook Islands, the decline of coral density in Bahrain, and the extent of mangrove deforestation in Pulan Redang Marine Park, Malaysia. (The downside is that remote sensing offers a snapshot rather than information on ecological trends.) The need is not simply to map resources, but to monitor them on an ongoing basis. To this end, the

Intergovernmental Oceanographic Commission of UNESCO, the U.N. Environment Program (UNEP), and the World Meteorological Organization agreed in 1996 to set up a global ocean-observing system and have it up and running by 2010.[70]

Satellites, which identified environmental trends such as greenhouse gases, ozone depletion, and climate change, have also revolutionized ocean science. One European space agency satellite has a radar system that can detect ripples from undersea waves crashing against deepsea mountains. Altimeters located in space improve the accuracy of bathymetric maps, which record the shape and structure of the ocean floor, and allow scientists to monitor global tides and currents. Radiometers can now measure sea surface temperatures to within 0.25° Celsius, generating highly accurate records of heat transfer between oceans and the atmosphere. A program known as SeaWiFS (Sea-viewing Wide Field-of-view Sensor) collects high-resolution ocean color data that register chlorophyll, water clarity, suspended sediments, and other parameters to monitor coastal water quality. These data are now available on the WorldWide Web.[71]

Technology can also play an important role in studying species' behavior, protecting their populations, and regulating their capture. One-watt transmitters strapped to leatherback turtles now beam signals from 1,000 meters below the surface, so marine biologists can track their migration patterns. Researchers in Vancouver, British Columbia, use a video camera known as FishTV to monitor feeding patterns of shrimp-like organisms. A hundred years ago, fishers would put one of their own high above the ship's deck to look for whales, tuna, and other large species. Later they employed hot air balloons, helicopters, and more recently, satellites and remote sensing devices to follow bluefin tuna and track dangerous ice and currents. In the Atlantic, some of the tuna are now tagged with pop-up transmitters to track their movement and record their origin in the hopes of ending bitter disputes over the conservation of western and eastern Atlantic stocks.[72]

Not all methods need to be high-tech. Recreational divers and fishers conduct rudimentary surveys to collect coral reef data for the global database known an ReefBase. Decisions can be made on the basis of direct experience and human knowledge and observation, rather than data collected by highly trained specialists. In tropical reef communities of the Pacific, some of the best conservation strategies—closed harvest seasons during the time when fish spawn, for instance—are based on years of practice managing resources.[73]

The World Bank recently endorsed the approach of combining human experience with computer technology and economic and scientific data to improve resource management. Taking inputs in largely descriptive terms, a computer program designed by Bank economists translates the information into quantitative assumptions. With the best scientific data and direct human observations, a user can go through a series of "what if, then" scenarios to yield a series of predictions and options. In Montego Bay, Jamaica, for example, the program showed that a combination of deep-ocean outfalls for residential and hotel wastewater and a reduction in discharges from an oil refinery could rebuild coral populations by as much as 12 percent. Local officials have used this analysis as the basis of a new zoning plan and watershed management program, and to justify the introduction of user fees at the Montego Bay marine park.[74]

To date, the technology that has made it possible to understand the ocean has been used to accelerate its destruction.

The Norwegian Pollution Control Authority has taken information-gathering tools one step further by setting up a warning system. The Authority is using radar satellite imaging to detect oil spills, establishing the world's first pollution alarm system. Since 1993, Norway has worked with Danish and other North Sea officials to install the detection network. Eventually, sea waters from Greenland to Estonia will be under their watch.[75]

Beyond the important task of guiding ocean management, there are broader reasons to study the oceans. With the first deployment of submersibles in the 1930s and more advanced underwater acoustics and pressure chambers in the 1960s, scientific and commercial exploration has helped illuminate both the geological history of the ancient ocean and current life in the deep sea. Ocean drilling and sampling has produced sediment cores that provide our best long-term records of natural climate fluctuations. Submersible observations (both piloted and robotic) have opened our eyes to hydrothermal vents and the unique life forms that surround them.[76]

Scientists, political leaders, and entrepreneurs increasingly look to oceans to meet pressing human needs for potable drinking water and new sources of food. If new technologies can be applied in a way that guarantees the health of oceans, then the oceans may also offer new sources of energy, minerals, biomedical compounds. However, each of these pursuits should be approached with extreme caution as they will undoubtedly expose the sea to new threats and exacerbate already serious problems of pollution and marine degradation.

In a world where sources of freshwater are quickly being depleted, people have looked to the ocean as a source of potable drinking water. Desalinated seawater currently accounts for just two tenths of 1 percent of world water use. In the future, desalinated seawater will continue to be a major source of freshwater for oil-rich arid countries, island nations, and a few countries that do not manage their water well, but it will probably not rise much above 1 percent of global water use by 2025. The downside of desalinization is that removing salt from water presents a disposal problem, and pumping the highly concentrated salt back into the sea can kill some species.[77]

Although still in the early stages of commercial development, offshore tidal, wind, and perhaps even thermal energy hold promise as economical and sustainable energy sources for next century. New technologies to capture power from ocean tides have been developed, particularly in Pacific island nations and Western Europe. The Philippines recently announced a contract with a Canadian firm to construct a

$100 million, 30 megawatt plant in the inshore reaches of the Sulu Sea. The project is on hold awaiting feasibility studies and approval by the government.[78]

Britain is further along in the process of making tidal power a reality. In 1998, England's IT Power received a $1.1 million contract from the European Union to design and construct an underwater turbine system by the year 2000. Resembling a wind farm 30 meters below the surface, the turbines will be powered by underwater tidal currents that flow between channels and headlands. Estimated to produce up to 300 kilowatts, the project is a collaborative effort between the power company, Germany's Kassel University, a Swedish turbine and generator manufacturer, and an engineering firm in Cornwall. The offshore oil industry has also lent expertise to projects such as this by developing more durable structures that are secured in the sea floor.[79]

Although tidal mills date back some 900 years in Europe, harnessing the sea's power has not been easy. Siting the subsea installations in areas within reach of a national power grid is difficult because only a few areas in the world have tides that are strong enough to make the effort worthwhile. The world's first attempt at a commercial wave power station, Scotland's Ocean Swell project (OSPREY), was abandoned after the waves that were intended to power it ripped it apart. Whether fueled by tides, currents, waves, or wind, power facilities in the ocean present a hazard both to ships and to marine species.[80]

Shell Oil Company is now actively seeking to develop offshore wind power in the North and Baltic seas. If the company does go forward with current plans, it could set an important precedent for oil and gas companies to invest in wind power stations, reducing demand for fossil fuel. Several northern European countries are also pursuing offshore wind power. Denmark, the world's second leading producer of wind energy, has ambitious plans. It now has one small offshore wind farm and plans to produce at least 4,000 megawatts of energy from floating structures at sea—about four times the current land capacity—by the year 2030.

Ocean thermal energy—created by the large difference between the temperature of warm surface water and that of cold deep water in the ocean—offers another potentially large source of energy. But efforts to capture this energy economically have been hampered by technological problems. Although production has yet to catch on in more than a handful of countries, cost-efficient technologies, growing markets for energy, and an unlimited supply of "fuel" suggest that oceans could prove to be a key player in the global energy economy in the coming decades.[81]

First discovered in the 1960s, highly concentrated deep-sea deposits of manganese, gold, nickel, and copper continue to tempt investors. Although mining in any location is difficult to contain, mining these materials is exceptionally risky: they are located along mid-ocean ridges far down in the Atlantic, Pacific, and Indian oceans under extremely high pressures. An international compromise on the deep seabed provisions of the Law of the Sea in 1994 has opened the way to some mining in international waters, but as long as mineral prices remain low, demand for minerals will probably be met from land-based deposits.[82]

One example that emphasizes the danger of deepsea mining comes from the Bismarck Sea. The Nautilus Minerals Corporation was recently awarded rights to explore massive sulfide deposits in the national waters of Papua New Guinea. Besides being rich in copper, zinc, silver, and gold, these areas are teeming with marine life that has adapted to unique chemical and heat conditions. Russian biologists, for instance, measured 5,000 animals in one square meter of chimneys (created by magma eruptions) that are being considered for mining. Guaranteeing environmental safety of underwater mining operations will require enormous effort and should be carefully thought through before proceeding. Once commercial mining begins, Nautilus expects to process 1,000 tons of ore each day.[83]

The promise of life-saving cures from marine species will soon become a commercial reality for bioprospectors and pharmaceutical companies. The first success story came in the early 1950s, when researchers isolated materials from the Caribbean sponge that led to the synthesis of the arabinosides, Ara-A and Ara-C. Each compound was found to have anti-viral properties that could be used to fight herpes; Ara-C was later discovered to have anti-tumor characteristics. Between 1977 and 1987, nearly 2,500 bioactive metabolites were identified from marine organisms. Though originally conducted in the Caribbean and Mediterranean seas, the search for new bioactive entities has spread to include almost all of the temperate and tropical seas, with selected expeditions into polar climes. Nearly a dozen medical-related compounds from different marine species have been identified and are in various stages of testing for direct human application and commercial development. (See Table 3.) [84]

The discovery of a new kingdom called *Archaea* is reshaping the way medical research is conducted. Although they are new to us, these microbes are named the "ancient ones" because they are thought to be the first life on Earth. They live on deepsea vents and chimneys, such as those near Papua New Guinea and the Galapagos Islands. An enzyme from one Archaean species, *Pyrococcus*, is the key to PCR (polymerase chain reaction), essentially the engine of DNA fingerprinting. With PCR, scientists can make billions of copies of a single strand of DNA in a few hours, allowing them to isolate and identify biological material. For his work in discovering the mechanism, American Kary Mullis won the 1993 Nobel Prize in chemistry. The discovery also led to the first marine microbe being sold commercially.[85]

Given how little we know about the ocean, tinkering with it for the sake of rapid commercial gain, whether from minerals or medicine, is shortsighted on several counts. First, the deep sea is dotted with oases of life that have been isolated for millions of years. Some of these life forms may harbor genetic diversity thought to have been lost through extinction, or other important clues about evolution. Researchers studying snails and worms that live at hydrothermal vents, for example, hope to reveal when animal and microbe symbioses first developed. Second, how we

TABLE 3

Examples of Therapeutic Compounds from Marine Species

Source Species	Compound and Use
Anti-bacterial/Anti-viral Compounds	
Sponge *(Tethya crypta)*	Arabinosides Ara-A and Ara-C, discovered in 1950, led to antivirals for herpes treatments with annual sales of $50–$100 million.
Indian seaweed & seagrass	Antiviral compounds; lab artifact not used in human applications.
Shrimp, lobsters, & crab	Shells contain enzyme chitosanase used against fungal infections; also the enzymes allow shells to be recycled and can serve as base for skin growth.
Anti-tumor Compounds	
Caribbean tunicate	Didemnins and ecteinascidins; being tested.
Dogfish	Squalamine.
Bryozoan *(Bugula neritina)*	Bryostatin, active against difficult-to-treat, fast-growing tumors such as lymphonas and melanomas.
Sea hares	Dolastatin.
Cyanobacteria/sea hares	Scytophycin and tolytoxin
Sponge	Ara-C.

choose to apply scientific and technological breakthroughs in the deep sea will have strong bearing on the health of oceans. Seabed mining in international waters is now subjected to some degree of oversight, but prospecting for living biological resources is still completely unregulated. Indeed, *any* ocean activity poses a risk to the health of oceans, particularly if we adhere to our present habit of exploiting resources in a free-for-all manner. Finally, the question of

TABLE 3 *(continued)*

Source Species	Compound and Use
Other Compounds	
Red algae	Kainic acid* used to fight parasitic worms such as hookworm.
Chinook salmon	Calcitonin* treats postmenopausal osteoporosis and bone disease.
Cod & shark	Liver oil contains Vitamin A and D.
Menhaden	Oil helps treat artherosclerosis.
Barnacle	Binding adhesive for tooth fillings, "Mother Nature's Super Glue," now being tested for biodegradable glues.
Stony corals & mother of pearl	Bone grafts.
Brown algae	Produces the agar that is used as a substrate in microbiology and also in food modifiers.
Archael hyperthermophile *(Pyrococcus)*	Heat-stable enzymes that promote faster, cheaper, and more efficient biochemical reactions; they survive at temperatures up to 104° Celsius, which kills off most germs. *Pyrococcus* is the key to PCR (polymer chain reactions).

* Originally from marine species, now made synthetically and by use of recombinant DNA techniques.
Source: See endnote 84.

who benefits from advances in knowledge of the global ocean commons—whether individuals and private companies or society as a whole—remains unresolved. The original parties involved in the Law of the Sea recognized many of these challenges: science and technology are referred to in 100 of the 320 articles of the Law of the Sea. International institutions and national governments are still grappling with these and other concerns.[86]

International Policies Take Shape

Because of the transboundary nature of ocean issues, international policies are vital to ensuring that marine resources are properly managed and protected. But for many years, the international institutions that were charged with managing oceans continued to treat them as a frontier for exploitation, rather than as a resource in need of conservation. In the last two decades, this pattern has begun to change. With support from member nations, scientists, and non-governmental organizations, international institutions have begun to forge a new era of oceans management: one that is based on viewing ocean resources as part of a larger ecosystem, rather than managing them for strictly commercial profit. The new direction employs the precautionary principle and rejects the traditional "fix-it-after-the-fact" approach. Although the framework for ocean governance is now largely in place, political squabbling and a lack of funding and enforcement still hamper progress.[87]

After nearly 25 years of extended and contentious negotiations, the U.N. Convention on the Law of the Sea was completed and opened for signature on December 10, 1982. On that day, 119 delegations promptly signed the treaty, showing strong and unprecedented support for what had been considered by some as an impossible task of laying down a convention to address issues concerning more than half of the Earth. The U.N. Secretary-General at the time, Javier Pérez de Cuéllar, called the convention "possibly the most significant legal instrument of this century." Although it took another 12 years to enter into force, when the required 60 nations had ratified it, the immediate and widespread approval of the text buttressed the chief premise of the law itself: that oceanic issues are closely interrelated and should be dealt with in a cooperative and mutually beneficial manner.[88]

Under the Law of the Sea, coastal nations were granted rights to use and develop fisheries within a 200-nautical-mile exclusive economic zone (EEZ). (Freedom of navigation was still guaranteed throughout the oceans, but only the high seas remained open to anything more than innocent passage.) With the privilege of controlling access came the responsibility to protect and conserve marine resources. In part, the convention formalized what was already accepted as customary international law—most notably, the right of national claims over the EEZ. But it also went far beyond existing practices.[89]

The Law of the Sea established a comprehensive framework governing ocean use and set such use in the context of environmental protection. Also for the first time, the Law of the Sea established a compulsory dispute resolution mechanism, referring unresolved issues to an international law tribunal. Rather than trying to address every individual concern and anticipate future issues, it recognized the need for parties to negotiate complementary and specific agreements.[90]

The most ground-breaking section of the law's text is Part XI, which established that the international seabed and its mineral resources are the "common heritage of mankind." This bold declaration reserves the international seabed exclusively for peaceful purposes, with adequate provisions for environmental protection, and provides for the wealth and benefits found there to be shared among all nations. In 1982, the United States refused to sign the Law of the Sea because the Reagan administration objected so strongly to the idea of sharing the wealth. Several industrial countries followed their lead and stalled the progress of treaty ratification.[91]

Beginning in 1990, the U.N. Undersecretary-General conducted a series of essentially private consultations to try to hammer out the differences between the negotiating parties and to pave the way for "universal acceptance" of the Law of the Sea. As a result of these meetings, the original language of Part XI, while far from perfect, was further altered in a 1994 implementing agreement. The agreement abolished production limitations and requirements for technology transfer, among other provisions. The 1994 changes to the law did pave the way for a number of additional countries to sign and ratify the law. By November 1998, a full 130 nations had ratified the Law of the Sea, more than double the original number of 60 countries that enabled the treaty to enter into force in 1994. But the United States is one of eight countries that still have not signed or ratified it. Although the Clinton administration and many environmentalists are in favor of ratification, the U.S. Senate remains opposed.[92]

At the same time that the Law of the Sea was evolving and coming into force, a series of related and complementary agreements were beginning to lay the groundwork for a new course of ocean management. Several treaties pre-date the Law of the Sea and have been amended according to more recent concerns. Focused primarily on oil spills and ocean dumping in the 1960s and 1970s, policymakers today employ a more comprehensive definition of marine pollution—one that includes land-based sources and routine shipping. A number of recent international laws call on nations to prevent pollution, protect habitat areas, and adopt the precautionary approach.

In 1967, well before the Law of the Sea was approved, the Liberian oil tanker *Torrey Canyon* ran aground off Britain's southwest coast, dumping 120,000 tons of crude oil (three times as much as the *Exxon Valdez* spilled in Alaska 22 years later). One in a series of highly visible disasters during the 1960s, this incident brought the horror of marine pollution to front pages worldwide and sparked international action. Working with national governments, the U.N. International Maritime Organization (IMO) (which was founded in 1958 to govern shipping) imposed strict safety and environmental regulations on the growing tanker industry during the 1970s and 1980s in an effort to stop ocean dumping and ship-based discharges, and to prevent accidental spills. Thanks to new rules requiring double-hulled construction, improved cargo-handling procedures, and more cautious operations in port and at sea, the volume of oil spilled into the oceans has dropped 60 percent since 1981, even though the amount of oil shipped has almost doubled.[93]

Of necessity, the IMO is slowly becoming more of an ocean steward. To address the biological pollution from shipping, the IMO's Marine Environment Protection Committee is drafting a legally binding Annex to the 1973 International Convention for the Prevention of Pollution from Ships (MARPOL). In a step that is long overdue, it is expected to require ships to exchange ballast waters offshore, where invasive species are less likely to take hold. In November 1998, the same committee agreed to prohibit ship paints from containing organotin and to develop standards for environmentally sound antifouling methods. (Marine paints containing organotin are restricted in the United States and banned from ships smaller than 25 meters in Europe.)[94]

The international MARPOL convention employs a ranking system to determine whether or not substances can be disposed of in the oceans. Annex I substances—certain heavy metals, radioactive wastes, oil and petroleum, and synthetic compounds—constitute the "black list" and are completely banned from dumping under any circumstances. The "grey list" includes materials that can be deposited with special care and permits, such as pesticides and large quantities of heavy metals. Critics argue that this approach essentially legitimizes hazardous dumping. However, wider application of this type of ranking system could control some substances until the time that they are phased out completely.[95]

The United States is one of eight countries that still have not signed or ratified the Law of the Sea.

A notable step in this direction came from the UNEP-sponsored Global Program of Action for the Protection of the Marine Environment from Land-Based Activities. At the January 1999 meeting, country representatives strongly supported a global ban on POPs. Advocates of the ban have singled out 12 persistent organic pollutants, including DDT, toxaphene, and dioxins, for elimination; others will be added in the future. Several are already banned in some countries. In 1997, the UNEP Governing Council agreed to finalize a binding global treaty by 2000 to reduce and eliminate POPs. More than 100 countries are currently involved in the treaty negotiations. A global ban would ensure that such chemicals are eliminated from use completely, rather than trying to contain damage later. This would continue the progress made with the oil spill regulation of the 1970s and 1980s toward a more precautionary approach.[96]

Member states of the 1992 Convention for the Protection of the Marine Environment of the Northeast Atlantic recently took an impressive step in support of this global ban. In September 1998, they voted to completely phase out by 2020 the dumping of hazardous substances in Northeast Atlantic waters, a region extending from Greenland to Spain and Finland. (See Figure 3.) [97]

The gradual institutional shift from a focus on exploitation of marine resources to their sustainable use can be seen in whaling. In the 1940s, for example, 14 whaling nations created the International Whaling Commission to promote conservation of whale stocks and development of the industry. During the 1970s, membership in the commission was dominated by pro-whaling nations. Quotas and scientific evidence were routinely ignored, enforcement was lax, and whale populations continued to be depleted. Public concern over whales in the late 1970s and early 1980s prompted a change in management procedures and an increase in the membership of non-whaling nations. Since 1986, the commission has banned *all* commercial whaling. This sets the important precedent of closing a fishery once it has exceeded the quotas, but enforcement has been difficult, and whaling for scientific and subsistence purposes is still allowed. Norway and Japan continue to increase their "scientific" take of whales.[98]

Traditionally an advocate for fisheries development, the U.N. Food and Agricultural Organization (FAO) has in recent years begun to voice concern about overexploitation and habitat degradation. A landmark FAO study in 1992 warned that 10 years after the Law of the Sea, many fisheries were at risk of biological collapse, the global fishing industry was losing $54 billion a year as a result of overfishing, and people were losing jobs and food. The report described the role that subsidies, excessive capacity, and other economic trends play in overfishing. FAO has since initiated a series of consultations on particular aspects of the global overfishing problem that have led to useful consensus statements, albeit without enforcement provisions.[99]

During the 1990s, the international community enacted several global agreements and policies aimed specifically at fisheries and marine conservation. In 1995, the U.N. Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks was finalized. Signatory states agreed to manage fish stocks that straddle EEZ boundaries and migrate across the high seas, including the highly prized tuna, swordfish, and shark fisheries that have suffered from severe overexploitation. More importantly, this convention marks the first international fisheries treaty or agreement to reject maximum sustainable yield as the standard for fisheries management, and the first to advocate a new standard: the precautionary principle, the idea of taking action before definitive scientific proof of damage is in hand. Marine concerns have also been integrated into broader international environmental policies, as evidenced by the oceans chapter of Agenda 21, adopted at the 1992 Earth Summit in Rio, and the 1995 Jakarta Mandate of the Convention on Biological Diversity. (See Table 4.)[100]

Proof that regional policies can pave the way for broader action at the global level comes from the South Pacific. In the late 1980s, the South Pacific Forum Fisheries Agency banned large-scale driftnet fishing in the region. (Extending out 50 to 60 kilometers in the water, driftnets snare large numbers of marine wildlife.) Prompted by the success of the regional ban and by international outrage over the environmental effects of driftnets, the U. N. General Assembly passed a moratorium on the use of this indiscriminate fishing gear on the high seas in 1991. As a result, the use of gigantic driftnets today has virtually ended on the world's oceans, though a few pockets of resistance persist in the Mediterranean and North Pacific.[101]

TABLE 4

International Ocean Policies in the 1990s, by Strengths and Weaknesses

U.N. Global Driftnet Moratorium, 1991

Strength: U.N. General Assembly passed global moratorium on high-seas driftnets in 1991. Use of this gear has virtually ended on the world's oceans.

Weakness: Eliminating this particular type of gear has led fishers to use longlines and other damaging fishing methods to evade the specifics of the moratorium, often with effects on marine wildlife similar to those of driftnets.

Oceans Chapter 17, Agenda 21, Earth Summit 1992

Strength: Addresses the sustainable use and conservation of marine resources and habitat areas. U.N. Commission on Sustainable Development addresses oceans and seas in 1999.

Weakness: Language with respect to conservation is weak, lacks specific commitments.

FAO High Seas Fishing Vessel Compliance Agreement, 1993

Strength: Global binding agreement. Countries whose vessels fish on the high seas must ensure that those vessels do not undermine accepted fishing rules; requires countries to provide FAO with comprehensive information about vessel operation.

Weakness: Not yet in force. Only 12 of necessary 25 countries have ratified it.

U.N. Convention on the Law of the Sea (entered into force in 1994)

Strength: Global agreement provides comprehensive framework for ocean development. Calls for balance between use and conservation; 130 nations have ratified it.

Weakness: Conservation obligations weak.

FAO Code of Conduct for Responsible Fisheries, 1995

Strength: More than 60 fishing nations have agreed to it. Contains principles for sustainable fisheries management and conservation; highlights aquaculture, bycatch, and trade.

Weakness: No punishment for ignoring this voluntary code. No mention of subsidies.

TABLE 4 *(continued)*

U.N. Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks, 1995

Strength:	Prescribes precautionary approach to fishery management both inside and outside EEZ, vessel inspection rights in accordance with regional agreements. Provides binding dispute resolution.
Weakenss:	Not yet in force; falls short of the required 30 ratifications. Only four of the top 20 fishing nations have ratified it.

Jakarta Mandate, Convention on Biological Diversity, 1995

Strength:	Adopted guidelines and general principles that call for the protection of marine biological diversity and sustainable use of marine and coastal resources. Puts ocean use in broader context of biological and social goals.
Weakness:	Guidelines too vague to be enforced.

Source: See endnote 100.

Several regions now prohibit particular activities in fragile marine areas. The Antarctic Treaty System reserves the region for strictly peaceful and scientific study. Through regional agreements, Latin American and South Pacific nations designated their waters as Nuclear Free Zones in 1967 and 1985, respectively, which means that testing, deployment, and use of nuclear weapons are banned. Representing about one third of the world's oceans, the International Whaling Commission has earmarked the Southern and Indian oceans as whale sanctuaries.[102]

Establishing a global network of protected areas would be helpful to conserve unique marine biological areas. By limiting accessibility and easing pressures on the resource, marine protected areas allow stocks to rebound and provide important refuge for threatened species. Globally, more than 1,300 marine and coastal sites have some form of protection on paper. But most lack effective on-the-ground management. The World Heritage Convention, which identifies and protects areas of special significance to humankind, lists only 31 sites that include either a marine or a coastal component, out of a total of 522, yet another sign of terrestrial bias. Many experts argue that the World Heritage List could be extended to a number of marine hotspots and should include representative areas of the continental shelf, the deep sea, and the open ocean.[103]

Designation of large marine ecosystems is an important sign of progress toward an ecologically based approach to ocean management. Scientists have named 49 large marine ecosystems worldwide, each based on similar biological, chemical, and physical characteristics rather than political boundaries. The Global Environment Facility (GEF) and the World Bank have endorsed this approach by pledging $300 million to support projects dealing with transboundary international waters issues. To date, 58 developing countries have submitted proposals, each with the approval of their Ministers of Environment, Fisheries, and Finance. The U.S. Congress, the Ecological Society of America, and the environment ministers from the North Sea countries have also endorsed the large marine ecosystem concept.[104]

The Gulf of Guinea Large Marine Ecosystem of West Africa shows how such an approach would work. With funding from the GEF and the World Bank, and technical assistance from two U.N. agencies, the six Gulf of Guinea countries—Benin, Cameroon, Ivory Coast, Nigeria, Ghana, and Togo—will soon collaborate on regional marine conservation efforts. The environment ministries will initiate a nonhazardous waste exchange program to control marine pollution and apply new technologies to profitably recycle materials from oil, gas, mining, steel, and agricultural industries that would otherwise leak into the Gulf. Linking together more than 350 specialists in this West African region, the program provides for the latest in technology, including satellite imagery and electronic sensors to detect contamination, as well as vessels to patrol. Currently, the Gulf of Guinea provides $3.8 billion annually to the region. With these cooperative efforts to prevent pollution and combat overexploitation of the region's marine and coastal resources, the marine ecosystem could provide an estimated $9 billion in sustainable socioeconomic benefits each year.[105]

Realizing the long-term payoffs from ocean protection requires large investments up front. In spite of its comprehensiveness, the Law of the Sea makes no mention of funding for ocean monitoring, enforcement, or research. One way to pay for these important and necessary functions is to charge a flat fee on everyone who uses oceans and channel the money into a global oceanic protection fund. As early as 1971, Elisabeth Mann Borgese of the International Oceans Institute proposed an ocean development tax of 1 percent on the utilization and consumption of oceans, that is, "all fish caught, oil extracted, minerals produced, goods and persons shipped, water desalinated, recreation enjoyed, waste dumped, pipelines laid, and installations built." She recommended that such money be levied by governments and administered through an existing ocean institution such as the Intergovernmental Oceanographic Commission of UNESCO "for the purpose of building and improving ocean services." In other words, a tax on the use and wealth of the commons for the sake of the conservation and management of the commons. The 1998 report by the Independent World Commission on Oceans marking the U.N. International Year of the Ocean strongly supports this idea.[106]

With shipping, fishing, drilling, and coastal tourism today generating more than $500 billion in revenues a year, an oceanic protection tax of just one tenth of 1 percent would generate $500 million per year. Such a tax would be fair and politically viable as well as ecologically sound since it would charge all users, industrial and recreational, based on their use and enjoyment of oceans. As an added incentive, companies could be eligible for a short-term exemption from the universal user tax by actively participating in ocean protection efforts. Administered through an international oceans organization as Dr. Borgese recommends, a global oceans protection fund could also provide seed money to jump-start new ocean-friendly initiatives, such as tidal energy projects in developing countries.[107]

In order to pay for actual damage to the global commons, the IMO administers an International Oil Pollution Compensation Fund which was set up to pay for oil spill clean-ups and related damage. A related convention establishes strict liability for tanker owners and creates a system of compulsory liability insurance. Although the system is imperfect—liability for environmental damage is limited and monetary liability is capped according to vessel tonnage—the existence of a fiscal mechanism to handle the cost of cleaning up oil spills creates an important precedent for other forms of pollution.[108]

Recent policy initiatives fill some of the void in international law, but many agreements are still not ratified. In many instances, conservation provisions are too vague to serve as adequate standards. More work is needed to meet international obligations to conserve marine resources as spelled out in the Law of the Sea. Some countries have begun the difficult task of strengthening current international laws at the national and regional level, essentially filling in the details needed to fully implement ocean protection agreements.

Besides creating the framework for future treaties, international and regional policies have begun to change expectations and raise awareness. Leaders can use these policies as leverage to encourage national governments, non-governmental organizations, public citizens groups, and industry representatives to become more involved in marine conservation. Indeed, this may be the Law of the Sea's most important legacy: empowering people from coastal and landlocked nations both North and South to work together toward the common goal of protecting our oceanic heritage.

National and Local Efforts to Protect Oceans

Because the most productive areas of the oceans are under national jurisdiction and 80 percent of pollution originates on land, addressing global marine issues also requires strong national actions. A number of policy tools implemented at the national and local level can help protect oceans, including coastal and marine zoning laws, bans on oil drilling and other destructive practices, trade measures, taxes, and fees. Many such programs currently exist but they need more funding, public support, and enforcement to improve their effectiveness. It is also essential to reduce fishing subsidies and impose stiff financial penalties for illegal dumping, pollution, and habitat degradation. Ultimately, protecting oceans comes down to ensuring that the goals that are well expressed on paper are actually put into practice. And this means working with people who live in coastal areas and depend on oceans for their living.

The first essential step is to view marine resources as part of a larger ecological system, rather than simply as commodities to extract. Integrated coastal management is one tool that can bring about this change. Under this community-based approach, diverse groups of people—fishers, tourism operators, developers, traders, the general public, and politicians—identify their shared problems and goals. The key is to agree to workable and cost-effective solutions that preserve environmental quality while meeting social and economic needs. National authorities have a practical role to play by providing funding, technical assistance, and legislative mandates that empower local officials and community members to enforce the laws. Currently, 90 countries are working to establish coastal management programs, but fewer than 20 have implemented them yet.[109]

Ecuador's experience with coastal zoning demonstrates the effectiveness of the coastal management approach. During the 1980s, vital mangrove swamps were virtually clearcut for intensive export-oriented shrimp ponds. A 1985 national ban on mangrove cutting was not enforced. By 1991, the country had lost more than 80,000 hectares of its original coverage of mangroves and salt flats, precipitating the collapse of small-scale shrimp fisheries. Coastal waters became polluted with excessive nutrients from aquaculture facilities. Meanwhile, pressures from expanding tourism facilities, coastal cities, shipping companies, oil refineries, and fish processors intensified.[110]

In 1986, Ecuador began a long and concerted process of reclaiming control of its coastal resources. Working with several national ministries, local organizations, and coastal resource specialists from the United States, and with financial support from the U.S. Agency for International Development and the Inter-American Bank, the country now boasts six special area management zones for the coast, each of which has a detailed resource management plan. Representatives from the forestry and fisheries departments and the Ecuadorian Tourism Corporation head up coastal law enforcement units, known as Ranger Corps. Working with local inspectors, Ranger Corps enforce laws, oversee mangrove forest practices, monitor water pollution, protect fisheries, and maintain a visible presence in coastal communities. Several other countries, including Sri Lanka, Thailand, and the Philippines, have followed a similar strategy by involving the people who rely most heavily on the coasts in their protection and guardianship.[111]

Some countries have gone a step further and banned particularly damaging activities, such as oil drilling and shrimp farming, in sensitive waters. For example, oil drilling is banned in U.S. waters off California and the North Atlantic seaboard under a 1990 oil drilling moratorium that was recently extended by President Clinton until 2012. In 1996, the Supreme Court of India upheld a ban on all industrial shrimp farms from within 500 meters of the high-tide line to protect valuable coastal areas. Thailand's Ministry of Agriculture banned the conversion of rice paddies to shrimp farms in mid-1998.[112]

Each of these cases represents an enormous political step forward on behalf of marine resource protection. But each ban is also subject to ongoing challenges. Canada's Atlantic waters, for instance, have been under a drilling moratorium for several years. With the collapse of valuable cod and haddock fisheries in Newfoundland and Nova Scotia, however, several oil companies are trying to get this policy changed by luring out-of-work fishermen over to their side with the promise of lucrative drilling jobs. Realizing the enormous risks posed by opening these rich spawning grounds to oil drilling, most fishermen's groups and environmentalists are opposed to the idea. As in so many other marine areas, preserving the renewable resources of the Canadian Grand Banks depends on policies that favor the long-term ecological health of a region, not simply short-term economic gain. The task also depends on officials who are committed to the goals of marine conservation and who will support such policies when they are challenged.[113]

The trade-offs between short-term economic gain and long-term ecological health are particularly evident in the tourism industry. From Bali to Belize, tourists expect to enjoy a clean coastline and uncrowded beaches. "Tourism is the future of the Caribbean. But... [i]f we are not careful, we will end up with loads of hotels, but no beaches and tourists," says the former president of the Caribbean Hotel Association. By building in sensitive areas, often using scarce water, and attracting visitors to biologically unique areas, often with few safeguards to protect the natural environment, coastal tourism itself exerts enormous pressures on the marine environment. Recognizing the risks of overrunning its beaches, the government of the Maldives now restricts building to atolls further out from the islands where development has traditionally concentrated, in a careful attempt to limit congestion and environmental damage, but the problems persist.[114]

Protecting oceans means working with people who live in coastal areas and depend on oceans for their living.

The tourism industry not only has a vested interest in protecting marine areas but also the means to do so. It is the fastest-growing industry in the world and by some measures the largest. Engaging industry partners by showing them how protection is in their best interest and then involving them in solutions will be key to ensuring that tourism is sustainable. Currently, Royal Caribbean Cruiseline, the Ecotourism Society, and three Caribbean communities are holding a series of public meetings to write guidelines for sustainable tourism in that region. Although voluntary guidelines are a first step, far more stringent regulations and enforcement are needed to crack down on illegal actions. In 1994, and again in 1998, for instance, Royal Caribbean Cruiseline illegally dumped oily wastes and then withheld information about the incidents from the Coast Guard, according to a recent U.S. Justice Department inquiry.[115]

Most communities cannot afford to dismiss the economic benefits of tourism, but neither can they afford to let temporary visitors dictate the health of their home. As a result, some communities are charging visitors a fee to help pay for resource protection. The island of Bonaire in the Caribbean has successfully adopted a fee system and has been able to fund a "diver's paradise," devoting a large proportion of diving fees to upkeep of the many and varied dive sites. A similar approach has been adopted in Saba Island, Lesser Antilles. In Bazaruto, Mozambique, a $5 fee is collected from tourists entering the country's only marine park. The money funds two full-time educators and monitors, with the rest channeled into community schools and health clinics. In Transkei, South Africa, hotel tariffs are directed back into the local community for schools, health clinics, and water supplies.[116]

In addition to coastal zoning and development laws, trade rules may become more widely used for purposes of marine conservation, although they are highly controversial. The United States, for example, has enacted laws that restrict or prohibit the importation of fish and wildlife products from other countries that do not meet certain environmental criteria. Two of them—the Marine Mammal Protection Act and the Sea Turtle Conservation Amendments to the U.S. Endangered Species Act—illustrate how trade restrictions can be used to promote the conservation of marine resources.[117]

The Marine Mammal Protection Act prohibits imports of yellowfin tuna into the United States from countries whose tuna-fishing vessels operating in the eastern Pacific Ocean do not meet U.S. dolphin protection standards. But trade embargoes resulting from this law prompted two separate challenges before dispute resolution panels of the General Agreement on Tariffs and Trade (GATT)—by Mexico in 1991 and by the European Union in 1993. In each case, the panel ruled in favor of foreign tuna fishers, holding that trade regimes (particularly unilateral ones) do not permit distinctions between otherwise "like" products on the basis of how they were produced. Although neither decision was implemented, the cases prompted the United States and 11 other countries whose vessels fish in the region to negotiate a multilateral agreement establishing an International Dolphin Conservation Program to be overseen by the Inter-American Tropical Tuna Commission. The new agreement sets common standards for dolphin protection and provides for comprehensive monitoring and observation of the fishery.[118]

The law protecting endangered sea turtles prohibits U.S. imports of shrimp captured in ways that harm these animals, requiring the use of turtle excluder devices or some comparable gear. Embargoes resulting from this law have encouraged some Latin American and Asian countries that wish to continue selling their shrimp in the lucrative U.S. market to improve sea turtle protection measures. India, Malaysia, Pakistan, and Thailand, however, challenged the law in the World Trade Organization (WTO). In October 1998, the Appellate Board of the World Trade Organization ruled that the way in which the United States was implementing its law conflicted with international trade rules. The Board emphasized that it is preferable for environmental standards—such as those relating to the protection of sea turtles—to be established on a multilateral basis, rather than a unilateral one.[119]

Although the WTO frowns on using trade restrictions to promote environmental goals, it also takes a dim view of subsidies. Its Committee on Trade and the Environment issued a policy statement on fishing subsidies in March 1998, a topic receiving increasing scrutiny from national governments, regional organizations, and the FAO. The possibility thus exists to use WTO rules to push for the removal of subsidies that promote overfishing.[120]

A 1998 study by Matteo Milazzo for the World Bank concluded that Japan, Russia, China, the United States, Norway, and the European Union pay about $20 billion each year in subsidies and price supports that encourage expansion of fishing fleets and overcapacity. Data from these countries show that government-funded subsidies equal one fourth of the revenues from marine fish catches.[121]

Diesel fuel tax exemptions provide a vivid illustration of how fishing subsidies work. In the United States, Russia, Japan, Taiwan, and most of Europe, diesel fuel used in fishing and shipping is exempt from standard fuel taxes. Because fuel comprises a large share of operating costs, the exemptions were originally intended to shield fishing and shipping industries from oil shocks in the 1960s and 1970s. This subsidy has been carried to its perverse extreme in Japan. Not only is the Japanese longline fishing fleet exempt from paying a fuel tax, it is even granted a rebate. The approximately 250 Japanese tuna longline vessels that captured highly valued tuna and billfish in 1996 received $91 million in fuel rebates, an indication of the enormous political clout of the industry.[122]

An international plan of action addressing fishing overcapacity was approved in early 1999. The plan calls for phasing out subsidies. Whether from FAO or the WTO, international attention is important, but the critical determinant is grassroots pressure from within the four national governments and the EU that are directly responsible for continuing these annual handouts. Besides eliminating false economic signals, phasing out fishing subsidies would free up an enormous amount of money that could be channeled into oceans research and monitoring.[123]

Although implementing a global ocean tax to pay for ocean management may not be practical for a long time, several countries have recently adopted individual taxes and fees with some success. New Zealand, for example, charges fishers a fee to pay for some of the costs of management. Each fee is based on what is brought into port and counted as catch. Similarly, Iceland has a program that charges fishers who participate in a quota system for the costs of monitoring and enforcing those quotas. The charges are limited to 0.2 percent of the value of landed catch. And the U.K., Norway, and Denmark all tax offshore oil and gas production in their waters.[124]

Finland charges vessels an "oil damage levy" on all oil imported to, or transported through, the country. Compared to their single-hulled counterparts, vessels that are equipped with a double hull and therefore less likely to leak are charged at half the rate per ton of oil. All revenue from this tax goes to an oil damage fund managed by the Finnish Ministry of Environment. When necessary, funds are used to cover the costs of oil-related environmental damage.[125]

In combination with outright bans and prohibitions, taxes on harmful practices provide strong deterrents against ocean degradation.

In combination with outright bans and prohibitions, taxes on harmful practices provide strong deterrents against ocean degradation. At their present levels, though, these taxes are generally too low and too dispersed to do much good. In the long run, there may be greater potential to use taxes and fines to protect the oceans, perhaps by imposing them directly on ocean dumping, fishing in overfished areas, and pollution.

Despite some small steps forward, commercial interests and merchant industries basically still hold sway over the terms of ocean governance. Scientists' calls for precaution and protective measures are too often ignored by policymakers and private companies, who tend to focus on enhancing profits and commerce with little regard for the effects on marine species or habitats. Overcoming interest groups that favor the status quo requires building a vocal constituency for ocean protection and clarifying the stewardship obligations that come with the privilege of use.

Cultivating Marine Conservation

Given recent progress in international and national laws and ongoing developments in science and technology, we now have a unique opportunity to rejuvenate the notion of cooperative governance of the oceans and to respond to the multinational reality created by transboundary pollution problems, but only if we act quickly. As essential as these advances are to ocean protection, they cannot form an effective whole without public awareness and participation. Unless a broad range of people adopt the cause of nurturing oceans, efforts to improve our knowledge base and political institutions will falter in the long run.[126]

To bring life back to the oceans, we need to make them more visible and to reorient the way we think of them. Traditionally, ocean issues have been publicized by a few dedicated spokespeople, such as the late Jacques Cousteau. He leaves an important legacy of excitement about oceans, allowing people to connect with these vast habitats in human terms. But the base of support for oceans needs to be broadened to include people who may not realize that they have a stake in the health of oceans. Enlisting the help of someone like David Hasselhoff, for example, the lead character on one of the world's most popular television shows, "Baywatch," with nearly 1 billion viewers in 140 countries, could bring new interest to marine conservation issues.[127]

People also need to participate in ocean management in concrete ways that reinforce the connections between land and coastal water quality. Hands-on learning and active participation in protecting oceans can cultivate a greater awareness of problems, encourage public involvement, foster new partnerships, and build a strong base of political and economic support.

From bird-counting events and Mussel Watches—in which shellfish are collected and tested for signature contaminants—to beach clean-ups, the ways in which people can get involved in ocean issues are virtually endless. Since 1986, the U.S.-based Center for Marine Conservation has organized an annual cleanup in coastal areas. Originally focused on North American beaches, the effort has gradually spread to other continents. In 1992, for example, several hundred people turned out for the coastal cleanup held in Venezuela. They collected about 25,000 kilograms of marine debris on a stretch of coastline 14 kilometers long. Today, people from more than 100 countries are involved in what is now the largest volunteer effort to collect data on the marine environment in the world. This is not an entirely new idea. The U.S. nautical charts on which the Coast Guard and sailors depend so heavily are based on the work of volunteers during the late 19th and early 20th centuries who took measurements whenever they were at sea.[128]

Many existing resources and networks can be tapped for education and participation. An estimated 35 million people visited a U.S. aquarium in 1997, each taking an image of oceans and marine life home with them. In Baltimore and Boston, public aquaria have children's programs, marine science libraries, public lectures, and special exhibits focusing on local and global marine issues. Some organizations encourage schools to adopt a particular section of coastline to study how land and water uses affect the marine ecology. Schools can also connect with university research centers, public aquaria, fish hatcheries, Coast Guard and merchant marine academies, 4-H or extension agencies, and local water authorities to set up mentoring opportunities and science education projects.[129]

Hands-on community projects are often extremely popular—and ecologically successful. In the wake of destructive shrimp farming, mangrove replanting projects are now under way in the Philippines, Thailand, India, Sri Lanka, and Ecuador. Over the last 12 years, staff from the Pakistan branch of the World Conservation Union and the Sindh Forest Department have replanted 12,000 hectares of mangrove forest in the Indus Delta, home to 200,000 Pakistanis.[130]

The beginning of each new year marks a boost in coastal protection efforts in the U.S. state of Louisiana. A very successful program run through the state's Department of Natural Resources accepts discarded Christmas trees to use as natural fill in floating wood frames. The trees prevent erosion by trapping sediment. They also provide habitat for crabs, shrimp, fish, ducks, and other waterfowl. Besides restoring life to the bayou, the program is the department's most popular environmental awareness campaign.[131]

Despite desperate economic and political conditions in Indonesia, about 250 people worked to clear invasive species from coral reefs on North Sulawesi Island in February 1998. Volunteer divers and snorkelers removed a particularly destructive starfish called crown-of-thorns, thus demonstrating that community involvement can play a substantial role in protecting coastal resources. The cleanup was followed by training sessions for community residents to teach them how to regularly monitor reefs to avoid a reinfestation.[132]

Consumer awareness campaigns are also useful ways to bring the sea closer to home and to show that what we buy and eat sends a powerful message to companies. In January 1998, two American environmental groups, SeaWeb and the Natural Resources Defense Council, kicked off a campaign titled "Give Swordfish a Break" to advertise that North Atlantic swordfish stocks, listed on the 1996 IUCN *Red List*, are overfished. Many young swords are being caught to fill nets that would otherwise be empty. The groups' aim was to increase awareness that consumer demand was encouraging fishers to overexploit these and other migratory species. In response to the public pressure and media attention, restaurant chefs, consumers, airlines, and cruiseships agreed to stop buying swordfish. In June 1998, President Clinton called for a ban on catching undersized swordfish and expressed support for ongoing measures to allow swordfish to recover. The Marine Stewardship Council, an independent organization, will soon be issuing guidelines for fisheries products to qualify for an eco-label. The labels will enable consumers to easily identify fish products that were caught and produced in an environmentally sustainable manner. The U.K. supermarket chain, Sainbury's, and Unilever Company, which controls 20 percent of the whitefish market in Europe and the U.S., have already agreed to buy only certified fish beginning in 2005.[133]

People can also become involved in setting priorities and making decisions in matters such as coastal zoning and marine protection. Lobster fishers in Maine and small-scale fishers in India, for example, have developed effective community-based systems of managing fishery resources. After years of trial and error, people who rely on oceans for their livelihoods know a great deal about what works and what does not. Their collective experience represents a wealth of knowledge that can further enhance coastal and marine resource management.[134]

Traditionally out of the reach of international law, the Arctic ecosystem will soon benefit from the participation of indigenous groups in the decisionmaking process. In 1991, eight Arctic countries agreed to a non-binding environmental protection strategy to focus on the threats to Arctic people and wildlife from persistent organic compounds, heavy metals, radioactive materials, and petroleum. In 1996, eight Arctic countries and three permanent participation groups—the Inuit Circumpolar Conference, the Saami Council, and the Russian Association of Indigenous Minorities of the North—formed the Arctic Council to implement the strategy. Although the creation of a council by no means guarantees strengthened participation by indigenous groups, it does represent an important shift toward more inclusive decisionmaking.[135]

In the Philippines, environmental groups, the U.S. Agency for International Development, Peace Corps volunteers, and local communities have teamed up to write citizens' guides to coastal management laws and teachers' guides to coral reef ecology. Distributing the resources through fishers' coalitions, labor unions, and elected officials, several Filipino communities have since adopted bans against cyanide fishing and stricter laws of enforcement, limited access, and sustainable use based on community-defined priorities.[136]

Of course, short-term, hands-on projects cannot meet all needs. Much of what oceans require—habitat rehabilitation, pollution prevention, and a reduction in fishing and exploitation pressures, for instance—will consume years of sustained attention and collaborative government action. At the October 1997 Eco-Baltic conference, an official with the Baltic Marine Environmental Protection Commission in Finland warned that cleaning up the Baltic Sea environment could take 30 or 40 years. Other highly contaminated regions like the Black or Yellow seas could take longer. Sustaining these long-term efforts will require strong public backing.[137]

A number of specific steps are needed to advance ocean protection. First, governments working in close association with scientists and environmental groups can establish a global network of marine protected areas and associate these areas with a scientific research organization or non-governmental organization. Pairing the protected area with a particular institution allows people to protect biodiversity and improve the knowledge base of underrepresented ecosystems at the same time. Universities, existing conservation groups, and the large marine ecosystems networks can be used for information exchange, scientific monitoring, joint management, and collaboration. In other cases, it may make more sense to dedicate a science-and-education-oriented program to a particular marine protected area.[138]

Second, working with community leaders and the public, governments can adopt a broad scheme of marine zoning and designated use areas that marks particular regions—such as migration routes for endangered species—as off-limits to heavy industrial use. Such an approach is needed in the Sea of Okhotsk, where Russian oil and gas companies plan to invest $25 billion in exploration and development near Sakhalin Island. The reserves also lie in the summer feeding grounds of critically endangered West Pacific gray whales and close to a major earthquake zone. If drilling proceeds, it is unlikely that the species will recover. An earthquake would devastate the marine environment.[139]

Third, increased funding for basic ocean science and management programs is essential. A number of steps would help. Particular ministries and management bodies can impose fees and taxes to fund research and management costs, while coastal communities and marine parks can implement tourism fees with relative ease.

Fourth, governments can accomplish two goals at once by phasing out billions of dollars in fishing subsidies that essentially underwrite overexploitation. This money would be better used helping some fishers to transfer out of the industry.

Fifth, governments should move quickly to ratify international agreements and fulfill treaty obligations. Among the priorities are ratification of the Law of the Sea by the United States and Canada, signing of the migratory fish stocks convention by European and Asian fishing nations, and adoption of both a global ban on persistent organic pollutants and a protocol on land-based sources of pollution by all governments. Because the interpretation and implementation of many international agreements remain open to challenge, the U.N. General Assembly should spend more than just one day a year addressing oceanic issues. During the Seventh Session of the Commission on Sustainable Development in April 1999, governments and non-governmental organizations have an opportunity to press for a U.N. standing committee on oceans, something that exists for outer space but not for the seas.[140]

By implementing these and other changes, we can ground future ocean management in a recognition that the seas are limited. Only this basic awareness will make it possible to put measures in place to ensure that we do not exceed those limits. Such actions will enable society to reap untapped benefits from the oceans: marine species and microbes that make possible new medicines, new techniques for the control and removal of environmental pollutants, improved methods of seafood production to meet global food needs, and new energy sources and industrial substances. But until preventive measures are put in place and fully adhered to, the present course of exploitation will further undermine the health of oceans and jeopardize any future benefits.

Ultimately, the effort to manage and share marine resources can bring people together and help forge new alliances for sustainable development that are based on common interests and intergenerational equity. The task of proceeding forward now rests in our hands, for in the end we all have a stake in the health of oceans.

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