ONE

Our Oceans in Trouble

People who know the sea well know something is wrong. Children visit the sea and listen in disbelief to stories about the good old days. Then they grow up, have their own kids, tell their own stories, and understand something's missing, that their kids are being deprived of something that once brought them great pleasure. Sophisticated media coverage also increasingly highlights and documents these changes for us, but with each generation, the clock is reset and we forget what came before, minimizing the perceived change. Yet, one need only look at a map of the coast or walk around a coastal community to find names of places like Sheepshead Bay, where no one's caught a sheepshead in a generation; Halibut Cove, where no one may ever catch a halibut again; Jewfish Creek, where no one remembers the last jewfish; or Salmon Run, where the last run occurred before anyone alive today was born. In a very real way, we are losing our natural marine heritage and our biodiversity, and it matters.

Over a century ago, scientists first noted rapid changes occurring along the east coast of North America. According to the U.S. Commission of Fish and Fisheries, halibut from coastal New England had been nearly extirpated by 1878 (see the following quote). Dwindling cod stocks triggered a decline in landings from their historic peak in 1887, followed by other targeted groundfish species in the ensuing decades (Fig. 1.1; NMFS 1990). Natural oyster reef habitat had been virtually eliminated throughout the Chesapeake Bay and northeastern United States (Brooks 1996). Similar changes had already been observed in Europe. The following summary vividly encapsulates the changing sea state at that time.

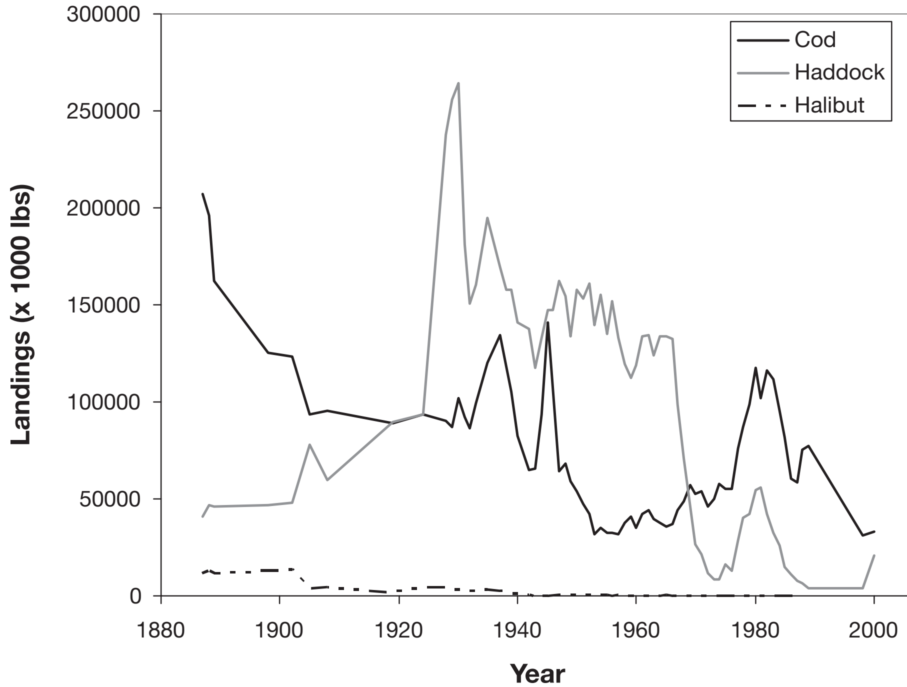

FIG. 1.1 New England Cod, *Gadus morhua,* Landings 1887–2002. Chronology indicates long-term decline in cod landings from a historic peak in the late 1890s, despite subsequent, temporary, and lower, interim peaks, and likely, increased effort. Latter peaks may reflect deployment or expanded use of new and more efficient gear, increased capacity or effort, geographic expansion, and stochastic changes in population(s). Other New England groundfish species show similar trends, though some show earlier (e.g., halibut, *Hippoglossus hypoglossus*) or later (e.g., haddock, *Melanogrammus aeglefinus*) peaks in landings. Source: Data from NMFS 1990 and 2002.

> Wherever . . . man plants his foot and the “civilization” is begun, the inhabitants of the air, the land, and the water, begin to disappear. . . . The fish, overwhelmingly numerous at first, . . . feel the fatal influence in even less time than the [terrestrial] classes. . . . The halibut, one of the best of our fishes, was so common along the New England coast as not to be considered worthy of capture. . . . It is only within [the last] few years that our people have come to learn their excellence and value, but they have already disappeared almost entirely from the inshores of New England, and have become exterminated in nearly all waters of less than five hundred feet in depth. (United States Commission of Fish and Fisheries 1880, p. xlv)

But this report represented a minority view. A century ago, the prevailing scientific and public views of the ocean’s living resources remained closer to this Thomas Huxley (1883) vision presented in his inaugural address to the 1883 Fisheries Exhibition in London: “Probably all the great sea fisheries are inexhaustible." Despite this oft-quoted proclamation, Huxley did acknowledge in his address that some fisheries, even some sea fisheries, were in fact exhaustible. The scientist within him could not ignore the empirical evidence that some of the fisheries he researched, notably the European oyster and certain salmon fisheries, had already been largely depleted.

But this did not change the conventional wisdom, that (1) little threat of endangerment, extirpation, or extinction existed for most marine species or ecosystems; (2) the well-documented vulnerability of a few notable exceptions, including some marine mammals, sea turtles, sea birds, estuaries, and coral reefs, extended to little else, especially most marine fish and invertebrates; and (3) the main targets of the world's great fisheries, which still retained a cloak of inexorable, and even magical, invincibility, were somehow immune to such outcomes.

For most of the past century, this dogmatic view remained dominant. Although in recent decades, minority voices within and outside the scientific community started to question it, the assumption of many was that managers could protect any individual species through tools like catch limits, gear restrictions, and other traditional tools. Without compelling evidence to the contrary, sustainable fisheries management was seen as achievable and just around the corner, using these tools, though perhaps needing better information and more political will.

To be fair, for much of human history, the oceans did seem relatively resistant and resilient to our actions, capable of both maintaining themselves and supplying a continued stream of fish, shellfish, and other valuable commodities. Areas undiscovered by fishermen or too far from port, too deep, or too difficult to fish for other reasons, served as "natural refuges" from fishing and protected intact marine communities. This helped maintain healthy marine ecosystems, protect biodiversity, and support fisheries. However, new and improved gear and technology, increased capacity, shifting targets, and rising market prices have enabled exploitation of both previously unfished natural reserves and formerly nontargeted species. As a result, these natural reserves have largely disappeared; their ability to help protect biodiversity, maintain healthy ecosystems, and replenish other fished areas is greatly reduced; and both the magnitude and geographic scope of fishing impacts have been greatly increased.

Slowly, the tide of scientific and public opinion is turning. Within the past ten years it has accelerated, approaching bore velocity, and the prevailing views on this may now be amid a phase shift. A few years ago, we still lacked a strong article in a prestigious journal or a consensus statement from a respected independent group of prominent scientists on the true scope of marine endangerment. We now have several (e.g., Jackson et al. 2001).

RISING TIDE OF MARINE ENDANGERMENT

While some questions related to the degree of extinction risk for marine fish and invertebrates remain lively topics, the same questions for marine mammals, sea birds, and sea turtles should have been resolved long ago. Human exploitation including fishing and other impacts clearly puts these animals at risk for extinction; the empirical evidence for their susceptibility is really beyond serious debate. Though less well known than their terrestrial counterparts, the rapid disappearance of Steller's sea cow (*Hydrodamalis gigas*), the Caribbean monk seal (*Monachus tropicalis*), and the great auk (*Pinguinis impennis*) (Roberts and Hawkins 1999) following brief contact with mobile human hunters in very different and geographically distinct ecosystems provides three of the most striking illustrations of their susceptibility. Steller's sea cow disappeared within just a few decades of contact with North Pacific whalers once seagoing whaling boats and technology arrived there. The Caribbean monk seal and great auk took slightly longer to succumb, but were still gone within a century or so of similar contact. The sea mink (*Mustela macrodon*) similarly disappeared from North Atlantic coastal waters by the close of the nineteenth century (COSEWIC 2002).

All of the great whales and sea turtles have teetered on the brink of extinction, but miraculously, none have thus far toppled from the precipice. Some have withstood extirpations, to which we lost the Atlantic gray whale (*Eschrichtius robustus*) (Mead and Mitchell 1984), along with the Atlantic walrus (*Odobenus rosmarus rosmarus*) (COSEWIC 2002). Others have seen dramatic declines such as those described for Caribbean sea turtles (Jackson 1997). All remain endangered or threatened and none have yet escaped extinction. Most have been given a respite through a complete or partial cessation of intentional, directed killing, but not all. Even some of those now fully protected from such directed take remain highly endangered. The northern right whale (*Balaena g. glacialis*) herd has been reduced to several hundred and continues to face threats from vessel strikes, entanglement in fishing gear, and minimum viable population size. Steller's sea lion (*Eumetopias jubatus*) likewise is still facing a suite of interlocking threats in the North Pacific.

Documented marine fish and invertebrate extinctions resulting from human impact are relatively few and less dramatic. Until recently, little attention has been paid to them. They remain more likely to go unnoticed, and threats to them are often more difficult to prove. However, there is a rapidly increasing suite of such organisms approaching the brink and a number that may already be extinct (Fig. 1.4). These include a diverse array of finfish, shellfish, and other invertebrates with a variety of life histories and distributions from around the globe. Perhaps most remarkable, the Canadian government recently listed two populations of the Atlantic cod, once seemingly ubiquitous across the North Atlantic, as endangered and threatened. Within the last three decades, the Newfoundland and Labrador cod population declined roughly 97 percent and the species virtually disappeared from some offshore areas (COSEWIC 2003).

The striking case of California's white abalone, *Haliotis sorenseni,* provides a clear and present example of the extinction risk posed to at least some marine species from targeted fisheries. This abalone occupied a relatively narrow depth range and small geographic range, but was fairly abundant in waters between 25 and 65 meters deep around California's Channel Islands until the early 1970s. At this time, a short-lived commercial fishery targeted this species, employing a handful of fishers for less than a decade. Within the span of just a few years, the fishery itself was extinct and the species was on the brink (Fig. 1.2). Commercial landings peaked at 65 tons in 1972, but plummeted to 0.15 tons in just four years. In the early 1990s, intensive searches in known habitats that once harbored densities of up to 10,000 abalone/hectare yielded only a few dozen. Abalone require minimum densities for successful fertilization and recruitment. There is no evidence of significant recruitment or landings in the last several decades. The white abalone appears to be approaching extinction, even though the brief, but intense, fishery that caused its initial collapse ended decades ago. Efforts are now being made to concentrate some of the few remaining adults in an attempt to facilitate successful reproduction, but it may be too late (Davis et al. 1996; Tegner et al. 1996).

The Nassau grouper (*Epinephelus striatus*), a large, long-lived species, formerly common throughout the Caribbean, provides another striking example of vulnerability to exploitation and associated extinction risk. Once an important apex predator, the dominant grouper on many Wider Caribbean coral reefs, and a species of considerable commercial importance, it is today absent or rare across much of the region. Where it still exists, it is much smaller and less numerous than it previously was. Despite its relatively broad distribution and once large numbers, it is exceptionally vulnerable to fishing. The Nassau grouper fears little, aggressively attacks baits, approaches divers, and eagerly enters traps. But the mating habits of the Nassau grouper may ultimately be its downfall. It is a protogynous (female first), hermaphroditic (sex-changing),

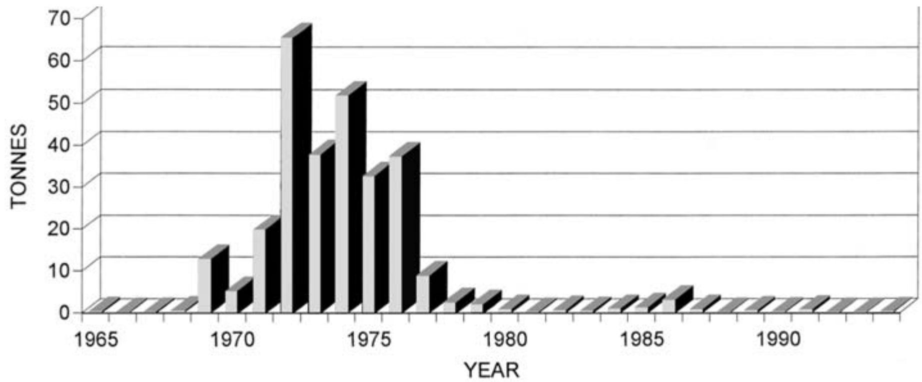

FIG. 1.2 California White Abalone, *Haliotis sorenseni,* Landings 1965–1994. Graph reflects reported commercial landings (metric tons). Landings for 1978–1994 include both miscellaneous abalone species and the white abalone. Period from 1969–1979 captures rapid rise and fall of short-lived commercial fishery executed by a handful of fishers for less than a decade that decimated population. Source: Davis et al., 1996; adapted with permission from the American Fisheries Society.

group spawner that aggregates in large numbers to spawn at specific sites for a short predictable time each year. These reproductive habits are a double whammy. First, the targeting of larger, older fish by fishermen means that the big males with greatest reproductive capacity are largely removed from the population. Nassau grouper are also very vulnerable to fishing while aggregating at their spawning sites, and fishers frequently target known spawning sites. Such aggregations once numbered in the tens of thousands of fish. At least a third of these once huge aggregations no longer exist. Despite closures to both spawning sites and targeted fishing, some aggregations and populations have not shown signs of recovery, possibly because measures came too late or because of continued bycatch. The Nassau grouper is currently listed as endangered on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List and a candidate species for the U.S. Endangered Species Act (ESA) (Coleman et al. 2000; Sadovy and Eklund 1999).

Australia's unusual spotted handfish (*Brachionichthys hirsutus*) provides a third striking example of a marine fish recently brought perilously close to and now teetering on the brink of extinction. So named because of its somewhat peculiar habit of walking on its fins rather than swimming, this fascinating species was one of the first Australian fish discovered and could be among the world's first lost due to human activity. The handfish is restricted to a narrow range within a single Australian estuary and is capable of only limited movement. It lays a small number of benthic eggs that remain on the bottom and have limited dispersal capacity. The primary threat to its continued existence is predation on its benthic eggs by the exotic northern Pacific sea star. This alien sea star, likely introduced via ship ballast water, is not a natural predator of handfish eggs. Trawling, dredging, pollution, modification of freshwater flow, and other activities that could disturb its estuarine habitat are also potential threats, as is any targeted collecting that may result from its rarity or value (Pogonoski et al. 2002).

Despite the increased recognition of extinction risk for fish, a proliferation of petitions to list fish under the U.S. ESA, and a growing list of additions to its candidate species list, until recently there remained no exclusively marine domestic fish listed on it. Prior to 2003, the only marine fish listed under the U.S. ESA were anadromous species that spawn in fresh or estuarine water, with the possible exception of the totoaba (*Totoaba macdonaldi*), a species that spawns only in the northern Sea of Cortez near the mouth of the Colorado River in Mexico. However, the eventual listing of a domestic truly marine fish under the U.S. ESA was only a question of when and which species.

On April 1, 2003, the listing of the smalltooth sawfish (*Pristis pectinata*) as endangered under the U.S. ESA answered these questions. This majestic and charismatic species may grow to 25 feet (7 meters) in length and bears a large sawlike snout responsible for its name (Fig. 1.3). Once common in the United States from North Carolina to Texas, dramatic reductions in range and numbers now largely restrict it to the extreme southern tip of the Florida peninsula and a population size less than 1 percent of its historical abundance. The current distribution is focused around Everglades National Park and Florida Bay, where it was once abundant enough to be the target of a recreational bow and arrow fishery. Commercial fisheries landings and incidental take were primarily responsible for reducing this species and bringing it to the brink of extinction, but typical of many endangered species, a multitude of factors, including habitat loss, pollution, modified water flow, and continued bycatch now conspire to keep it there or finish it off (NMFS 2003). Perhaps it was foolish to wait so long.

Prior to the sawfish listing, the totoaba was likely the most marine fish listed under the U.S. ESA. It provides another excellent and interesting example of how human activities, often acting in concert, can rapidly endanger a marine fish. The largest member of the drum or croaker family (Scianidae), the totoaba was endemic to and abundant in the Sea of Cortez (Baja California), where it aggregated to spawn in the lower reaches of the Colorado River. The common names of this family stem from sounds produced by vibrating their swim bladders. Mexican fishers initially targeted this species in the 1920s, primarily for

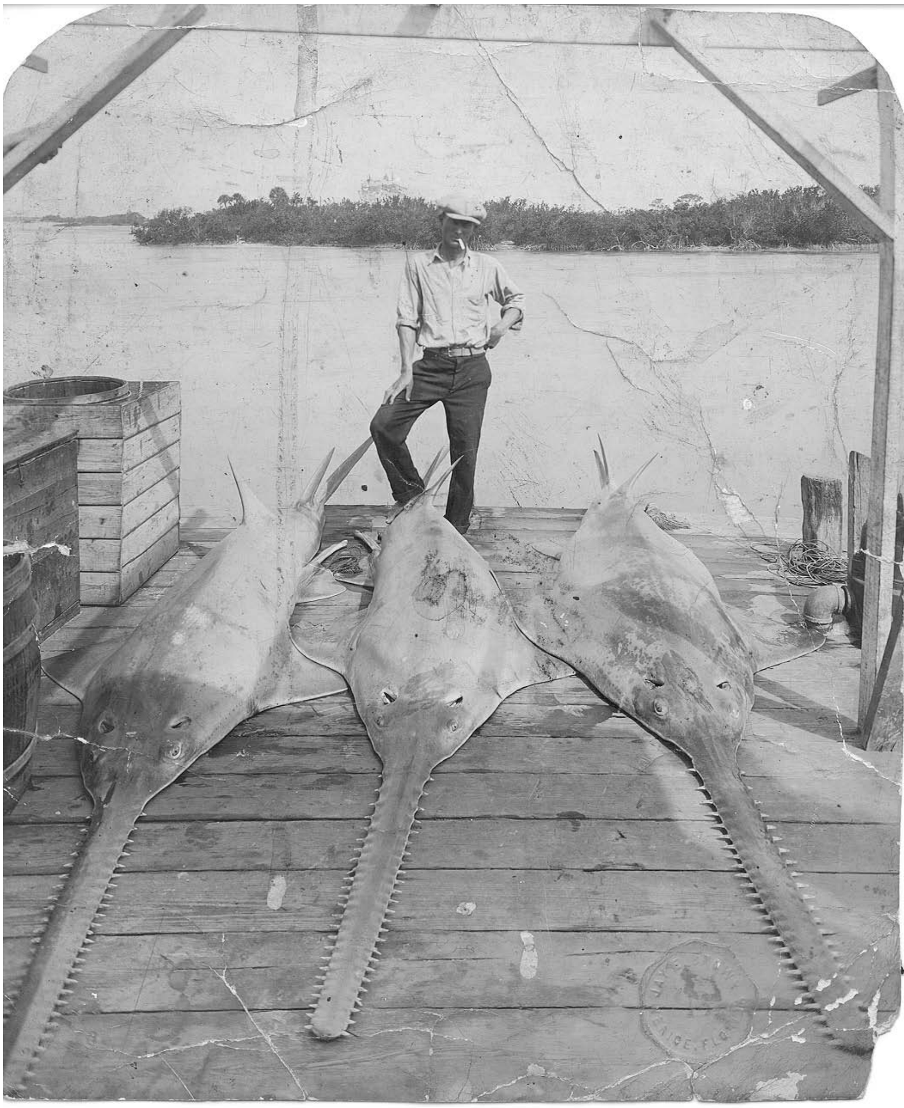

FIG. 1.3 Smallmouth Sawfish, *Pristus pectinata,* circa 1928. Historic photograph shows a day's catch of smallmouth sawfish taken off southwest Florida. Recently listed as endangered under the U.S. Endangered Species Act, these large predators were once common from North Carolina to Texas, but are now rare and largely restricted to a small area off of southern Florida. Source: Photo courtesy of Al Stier and www.floridasawfish.com.

their swim bladders and the high price they fetched in Asian seafood markets. Nonetheless, the catch peaked by 1942 at close to 5 million pounds and declined precipitously thereafter. Although the directed catch was clearly responsible for the initial decline of this species, damming of the Colorado River and bycatch from an intensive shrimp fishery subsequently furthered its decline and continue to endanger it (Norse 1993).

The growing list of petitioned and candidate marine species under the U.S. ESA and elsewhere reflects the increased risk and recognition of that risk and the extension of human impacts further offshore (Fig. 1.4). Among the truly marine species recently listed or petitioned are the barndoor skate (*Raja laevis*) in the New England region due primarily to bycatch; several groupers in the southeastern United States and Caribbean, including the Nassau grouper, due to both directed take and bycatch; the boccacio rockfish (*Sebastes paucispinis*) on the U.S. Pacific coast due to directed take and bycatch; and a number of marine fish from Puget Sound in Washington state, reflecting the increasing concern about the status of marine fish species throughout the country.

FROM SPECIES TO ECOSYSTEMS

> The diversity of life in the ocean is being dramatically altered by the rapidly increasing and potentially irreversible effects of activities associated with human population expansion. The most critical . . . contributors to changes in marine biodiversity are . . . fishing and removal of the ocean's invertebrate and plant stocks; . . . pollution; physical alterations to coastal habitat; invasions of exotic species; and global climate change. . . . These stresses have affected . . . life from the intertidal zone to the deep sea.
>
> —NRC 1995

In addition to its remarkable similarity to the observations of the U.S. Commissioner of Fish and Fisheries (1878) with which this chapter began, two important distinctions stand out in the NRC (1995) report, reflecting increases in both human understanding and impact in the last century. First, it defines *biodiversity* (a term unknown a century ago) to mean the variety or collection of life at three levels, genomes, species, and ecosystems, and recognizes that humans are now impacting all three. Fishing and other stresses are altering the genetic structure of some marine species, threatening or endangering the continued viability of others, and modifying complex marine ecosystems, including their associated species assemblages and physical environment. Equally significant, the NRC report recognizes the increasingly ubiquitous geographic scope of anthropogenic impact, which is no longer confined to nearshore, shallow water, or developed areas.

Because human populations contribute directly to all of the proximate stresses identified here, these stresses rarely occur in total isolation from one another and often result in cumulative impacts to species, genomes, and ecosystems. Depending on the nature of these cumulative interactions, the impacts

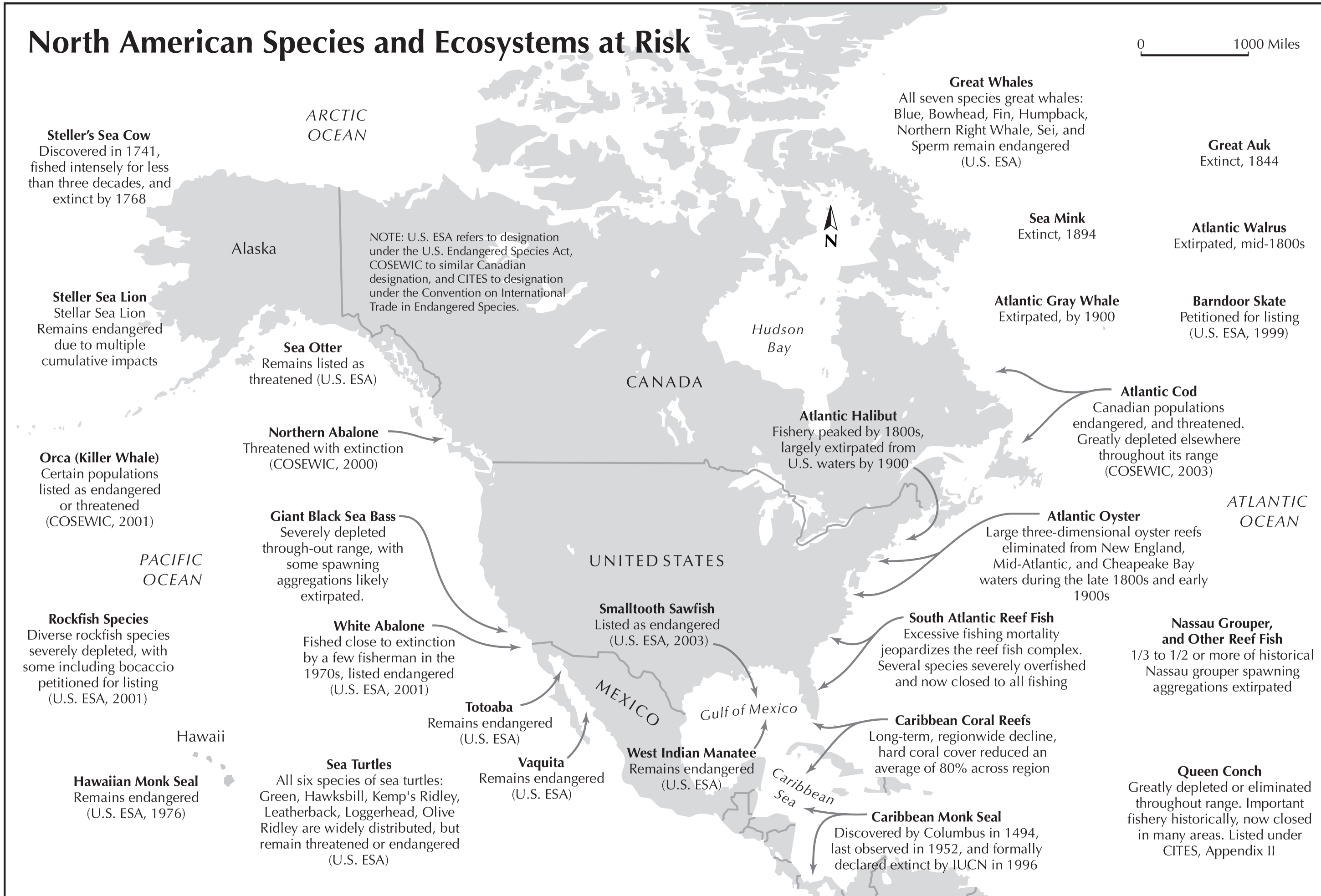

FIG. 1.4 North American Marine Species and Ecosystems at Risk Map. This figure highlights selected examples of species and ecosystems considered extinct, endangered, threatened, or at risk. Sources include COSEWIC 2002 and 2003; http://www.nmfs.noaa.gov/prot_res/; and Roberts and Hawkins, 1999.

are often synergistic. Fishing and related extractive activities are particularly widespread in the oceans and often remove critical components of ecosystems, making them more vulnerable or less resistant and resilient to other stresses, and are thus often implicated as key contributors to cumulative and synergistic impacts. Acting both independently and together these stresses have impacts ranging from the decline in important living marine resources, the loss of productive marine habitats, and reduced water quality to human health problems, mass mortality of fish and marine wildlife, and increasingly, population, species, community, or ecosystem endangerment or collapse. Furthermore, these anthropogenic stressors also interact with natural stressors, such as hurricanes, other storms, and climate variation (Jackson et al. 2001).

Despite the recognized gravity of these threats, a number of human and ecological attributes often frustrate our ability to fully understand, much less manage, them. These factors often heighten the threat to marine ecosystems and can include human ignorance and arrogance, scientific uncertainty, environmental variability, and biological complexity. Synergy, biocomplexity, ecological diversity, and redundancy in marine ecosystems can often delay, mask, or lead to their sudden collapse.

Ignorance and Arrogance

World-renowned marine explorer, scientist, and diver Dr. Sylvia Earle often states, "The single most frightening and dangerous threat to the ocean is ignorance" (Carless 2001). We have much left to learn. But we do already clearly know (1) that specific human activities are causing profound changes to our oceans, (2) what some of these impacts are, and (3) how we can use existing information to better protect our ocean resources. Ignorance becomes a much more powerful threat when matched with arrogance. It is often not how little we know that gets us in trouble, but how much we think we know. Our frequent failure to recognize the limits of our knowledge and act accordingly (i.e., in a precautionary manner) causes the harm. We often seem to believe that if we only studied a little more and got a little more knowledge, we'd be able to overcome uncertainty and effectively manage nature. Yet the more we learn, the more elusive that goal seems to become.

Uncertainty and Variability

Uncertainty and environmental variability are two similarly linked ecological attributes. Temporal and spatial environmental variability are among the most certain of ecological attributes. Even without human impact, both are nearly universally present and often of great enough magnitude to obscure otherwise reliable measures or indicators. An example of this is the frequent masking of the stock-recruitment relationship in fisheries management due to the high natural variability of key parameters that tend to mask the expected and widely held principle that there is a linkage between the size of an exploited stock and the level of recruitment. Although this widely held belief must be true at some level, the relationship can be difficult to detect or demonstrate due to the high signal to noise ratio. The high degree of natural environmental variability inevitably creates considerable uncertainty in many natural resource management decisions, especially those involving fisheries issues. Such uncertainty in the context of controversial management decisions nearly always leads to delay, inaction, or weak action, until it is too late to adequately protect the resource (Ludwig et al. 1993).

Ecological Complexity and Interdependence

The ecosystem is the basic and functional unit of ecology because it includes both living organisms (biotic communities) and their associated nonliving (abiotic) environment, each influencing the properties of the other and both necessary for maintenance of life as we know it on the earth. Any unit that includes all of the living organisms in a defined geographic area interacting with their physical environment in such a way that energy flow leads to clearly defined trophic structure, biotic diversity, and material cycles constitutes an ecosystem. Living organisms and their surrounding physical environment are inseparably interrelated and interactive with each other. The notions of ecological complexity, interdependence, and integrity extend the ecosystem concept to recognize the holistic nature and complex relationships within and among natural systems. Ecological (or bio-) complexity is "the dynamic web of often surprising interrelationships that arise when components of the global ecosystem—biological, physical, chemical, and the human dimension—interact" (NSF 2001). Ecological interdependence simply refers to the many, varied, and complex ways in which ecosystem components interact, affect, relate to, and depend on one another for their health and survival. These ecological attributes often greatly amplify the impacts of perturbations to individual components throughout marine systems and consequently exacerbate threats to our oceans. The following case of the spiny lobster in the Marcus and Malgas Isles illustrates this well.

Spiny Lobsters

Various members of the diverse, fascinating, and widespread spiny or rock lobster family (Palinuridae) play critically important ecological roles in both tropical coral reef and temperate kelp systems. They are among the most valuable and prized fisheries resources in the world and are the targets of intense commercial and recreational fisheries around the world. Spiny lobsters are technically considered omnivores, but frequently function primarily as mid-level carnivores within their marine benthic communities. As such, they govern the number and sizes of invertebrates like sea urchins, mussels, and gastropods (Lipcius and Cobb 1994).

Many aspects of the spiny lobster's biology are remarkable. For example, its early life history includes an incredibly long larval period that can last up to two years, cover hundreds or thousands of miles, and involve a dozen form changes. But no aspect is more fascinating than that revealed by its dramatically different fates off Malgas and Marcus Islands in South Africa. When studied in the 1980s, these adjacent "twin" islands shared similar physical characteristics, but dramatically different biological communities and food-web relationships that were stable and persisted over time, apparently representing alternative stable states (Barkai and McQuaid 1988).

On Malgas Island, the rocky habitat was dominated by seaweeds and by superabundant rock lobsters (*Jasus lalandii*), which constituted an extraordinary 70 percent of the total benthic biomass. Rock lobsters there consumed settling mussels and prevented the establishment of mussel beds. They also preyed on several species of whelks, though one whelk species was partially protected from lobster predation by a commensal seaweed that covered its shell, and other larger whelks were too large for the lobsters to eat. By contrast, Marcus Island maintained extensive mussel beds and large populations of sea urchins, sea cucumbers, and especially whelks, but lobsters were conspicuously absent. Whelks were less abundant, less diverse, and dominated by different species on Malgas. At some point, the lobster was lost as the key predator from Marcus Island and something prevented its return (Barkai and McQuaid 1988). But what?

An elegant series of experiments partially unraveled the mystery of Malgas and Marcus. Initial studies showed that selective predation pressure from lobsters on different whelk species on Malgas limited their abundance there. In contrast, the absence of lobsters on Marcus allowed for far greater abundance, diversity, and composition of whelk there. When lobsters were transplanted from Malgas to Marcus Island in cages and control lobsters were kept in cages on Malgas as well, all caged animals on both islands survived until their release over nine months later. In other words, there was nothing about the water quality, temperature, or currents that controlled their survival.

The next experimental step was to install artificial shelters on Marcus to ensure suitable habitat for lobsters there and then transfer and release a thousand tagged lobsters to them. This release produced sudden, dramatic, and remarkable results. The usually predatory and apparently healthy lobsters were engulfed, overwhelmed, and consumed immediately by hordes of whelk, their normal prey. Hundreds were attacked instantaneously and within days no live lobsters could be found on Marcus. To ensure that the lobsters hadn't been injured or otherwise made susceptible to attack in the tagging and transfer process, the experiment was repeated five additional times with smaller numbers of unmarked lobsters with similarly gruesome results. The results were all the more spectacular considering the lobsters' strong tail, rapid reverse swimming escape response, and armored shell. Close observations revealed that the lobsters initially escaped by flicking their tails, but each time they contacted the substrate, more whelk attached to them until their weight prevented escape. Lobsters were mobbed to death on average within fifteen minutes by more than 300 whelks that stripped them of all flesh within an hour (Barkai and McQuaid 1988).

According to local fishermen, lobster populations on the two islands had been similar to each other just two decades earlier. The cause of the initial disappearance of lobsters from Marcus Island remains a mystery and may have been due to either overfishing or pollution. Regardless of the initial cause, the whelk have proven capable of reversing their normal role as rock lobster prey and excluding them by aggressively preying on them when they return. Unlike lobsters, whelk can only prey on damaged mussels, not on healthy ones, and mussels are filter feeders obtaining their nutrition from the water column, enabling them to coexist at high densities when lobsters are excluded (Barkai and McQuaid 1988).

The Malgas–Marcus saga points out the complex, variable, and often hard to predict or see predator–prey, competitive, and other relationships that frequently exist among members of biological communities and between them and their physical environment. Certainly, as already noted here and as is well documented, spiny or rock lobsters often play critical roles in structuring a range of tropical and temperate benthic communities. For example, research on the role of fishing impacts on another spiny lobster (*Panularis interuptus*) in the dynamics of southern California kelp communities concluded that heavy fishing pressure on the lobster likely contributed to the release of sea urchin populations and the episodic destructive urchin grazing observed since the 1950s, with the associated urchin barrens and reduced kelp forest cover. Such fishing pressure reduces the number and density of lobster populations, and it also reduces lobster size (Fig. 1.5), which means that larger urchins escape being eaten by lobsters (Tegner et al. 1996; Tegner and Levin 1983).

Earlier, we mentioned the extreme intensity of many commercial and recreational lobster fisheries. To provide an idea of this intensity level for one fishery, the industrious, hardworking Florida Keys fishermen remove nearly all of the adult spiny lobster (primarily *Panularis argus*) from shallow water areas in less than half a year of fishing (Hunt 1994). Recreational lobster fishing is an important factor in the intensity of this fishery and can rival or even exceed the commercial catch in some areas (Blonder et al. 1988; Davis 1977; Eggleston and Dahlgren 2001). Scientists, fishers, conservationists, and others may continue to debate whether such current intense harvest levels are sustainable from a lobster fishing perspective, but given what we already know there should be little doubt that this level of lobster removal is likely having profound impacts on ecosystem dynamics, community structure, and nonconsumptive recreational activities. We may not know exactly what these are, what their extent is, or when they will manifest into a demonstrable collapse or problem, but we should be concerned.

In 1997, commercial lobstermen in the Florida Keys discovered an unusual and unprecedented sea urchin–sea grass overgrazing event (Fig. 1.6). Urchins were piled on top of one another in a mounded front 2 miles long at densities up to 364 per square meter. From September 1997 to May 1998 the urchin front consumed and denuded the valuable sea grass habitat within its path. The front eventually receded, but the damaged areas have still not recovered and there have been some less intense recurrences (Hunt 2001; Rose et al. 1999; Sharp 2000). We may never know whether this event was related to the lobster fishery or another anthropogenic or natural stress, but it is certainly plausible. What is clear is that the multiple interactions among species and stressors demonstrate that the largely single species approaches of the past, aimed at controlling one variable, such as fishing gear, or protecting one species, typically one of commercial value, are simply inadequate.

MARINE RESERVES: A HOLISTIC, ECOSYSTEM-BASED APPROACH

Long before species are threatened with extinction, the critical roles they play in maintaining healthy ecosystems are often impaired. While the number of

FIG. 1.5 Channel Island Spiny Lobsters from the "Good Old Days," circa 1960. Historic photograph shows size of lobsters caught during early days of scuba-diving off the Channel Islands. Source: Photograph courtesy of Dick Holt.

marine species facing biological extinction continues to grow, many more are becoming ecologically irrelevant or subject to ecological extinction. Still more remain ecologically relevant, but function in a reduced or altered capacity from an ecosystem perspective. Spiny lobsters do not yet face biological, ecological, or even commercial extinction, but have been severely depleted in many places. As a result, the ecosystem functions they once provided have been profoundly altered or lost, sometimes with dramatic consequences. In most ma-

FIG. 1.6 Florida Keys Urchin Overgrazing Event, circa 1997–1998. Photograph captures unusual and unprecedented event during which sea urchins were piled up in a mounded front over two miles long with densities up to 364 urchins/meter^2. The advancing urchin front destroyed valuable seagrass habitat in its path that has yet to recover. The cause of the outbreak remains a mystery. Source: Photograph courtesy of the Florida Fish and Wildlife Conservation Commission.

rine ecosystems, a myriad of species have been similarly depleted and their functional contributions lost or reduced. Globally, large predatory fish biomass has been reduced over 90 percent (Myers and Worm 2003). Depletion of a single predator can reverberate and impact a host of other species, yet we continue attempting to manage most species independently. What happens to species and ecosystems when you deplete an entire class of predators? As each thread of life is removed, the fabric that once stitched together marine ecosystems frays. The tearing apart and impairment of these living systems places even greater stress back on already depleted species. The resulting downward spiral often leads to collapse of species and ecosystems and must be reversed.

Marine "no-take" reserves, areas closed to fishing and all other extractive activities, are among the most essential tools required to protect and restore the health of our oceans from multiple stressors. Why? They are uniquely tailored to help prevent and reverse the downward spiral that results from removing critical components of living marine systems in areas subject to exploitation. At the most basic level, they are the only approach to marine resource management specifically designed to protect the integrity of marine ecosystems and preserve intact portions and examples of them. In fact, this is their primary purpose.

Protection of ecosystem integrity encompasses three components: ecosystem health, resilience, and potential for continued self-organization. *Ecosystem health* refers to its current state or condition at a point in time. *Resilience* refers to the ecosystem's ability to respond to additional stress caused by external influences. The final component refers to the ecosystem's capacity for development, regeneration, and evolution under normal circumstances (Kay and Regier 1999). Marine reserves contribute to the protection of ecosystem integrity by greatly strengthening and supporting each of the component parts of that integrity.

Marine reserves can function as a preventative or as insurance to maintain, protect, and restore healthy marine ecosystems. They can also serve as a cure: They can help restore and recover an ill or injured ecosystem. They can help stop the bleeding, stabilize and right the patient, protect the vital organs, and set them on a path to recovery. They also allow us to monitor them to provide critical data needed for decisions about additional therapy. For healthy systems, they may be employed as part of a comprehensive, preventive health maintenance program. For both, they can provide insurance via increased resilience to speed recovery following an unexpected or catastrophic event. Thus, increased stress only enhances their value. Ecosystems are inherently dynamic and the long-term goal should not be to freeze them at a point in time, but rather to maximize their options for continued evolution. Over longer time scales, the role of marine reserves in protecting ecosystems' capacity for continued natural evolution will likely grow and is among their most important.

Marine no-take reserves do not seek to protect just one species, control a single variable, or eliminate natural change. Rather, they aim to avoid anthropogenic perturbations to individual species and across whole ecosystems while supporting natural diversity, variability, and evolution. They preclude extractive or consumptive use within their boundaries but are essential to responsible, sustainable use outside their boundaries. Marine reserves do not allow fishing within their boundaries, but effective networks of them may be critical to optimizing and preserving fishing opportunities outside of them. Marine reserves need not ban nonconsumptive recreational activities and can enhance opportunities for such activities. Effective marine reserves do not require complete knowledge about individual species, their natural interactions, or the complex ecosystems of which they are integral components, but are essential to improving our understanding of each.

Marine reserves are likely the only tool for achieving certain conservation objectives, the best at achieving others, and a key contributor to achieving still others. Although necessary, they are not a magic pill or cure-all and not sufficient by themselves to protect the oceans from all human abuse independent of other measures.

MARINE PROTECTED AREA NOMENCLATURE: SPEAKING A COMMON LANGUAGE?

As highly regarded a management tool as marine reserves have become, there remains a great deal of confusion as to exactly what they are. Much of this relates to broader terminology issues because marine reserves are part of a spectrum of management mechanisms under the umbrella term *marine protected area* (MPA). Among the first things anyone new to MPAs notices is that there are a plethora of terms to describe them, the terms are not used consistently, and their names often bear no resemblance to reality or the level of protection they afford. Protected areas are often left unprotected. Sanctuaries frequently provide limited or no sanctuary for their inhabitants. Reserves are rarely held in reserve. What is called a sanctuary in one place is referred to as a reserve somewhere else. What is called an MPA by someone in one place might be referred to as a marine managed area (MMA) or marine conservation area (MCA) by someone else or in some other place. MPA to some people in some places is a very general term that covers a range of place-based protections, whereas to other people in other places it is a very specific term that connotes a very high level of protection. There is little consistency from place to place or within a place. There is little consistency or standardization among or within stakeholder groups. In short, confusion abounds.

MARINE RESERVE AND MPA TERMINOLOGY

> **Definition:** *Marine reserve = marine "no-take" reserve = an area of the sea in which all consumptive or extractive uses, including fishing, are effectively prohibited and other human interference is minimized to the extent practicable.*

The focus of this book is marine no-take reserves, or marine reserves for short. In the context of this book, we intend either of these terms to define an area of the sea in which all consumptive or extractive uses, including fishing, are effectively prohibited and other human interference is minimized to the extent practicable. Both within and beyond the scope of this book, we believe there is an advantage to and recommend using the longer term, *marine no-take reserve,* whenever possible, to make the meaning more explicit, given the variable usage of these terms and the resulting confusion. Of course, one must explicitly define these terms when they are used in new contexts or with new audiences for the same reason. This book discusses some of the nuances of this definition but will not dwell on or overemphasize them unnecessarily. Given the variable usage of and confusion regarding MPA terminology, there is no ideal term for the book's subject, but we selected the preceding term(s) and definition to be as clear, accurate, and consistent with other accepted terminology as possible, and to avoid unnecessary confusion.

For the purpose of this book, we define MPAs as distinct from marine reserves:

Definition: *Marine protected area (MPA) = "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment."* (Kelleher 1999)

The above definition, originally adopted by the World Conservation Union (IUCN) nearly fifteen years ago, is among the most widely used and accepted. Given the large and broad governmental and nongovernmental organization (NGO) membership of IUCN, this definition may be considered an international standard. The U.S. government similarly defined MPA as "any area of the marine environment that has been reserved by Federal, State, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources within them" in MPA Executive Order #13158 (The White House 2000). Both the nearly identical IUCN and U.S. definitions comport with the idea that MPAs include a broad spectrum of protective management regimes with variable levels of protection for ocean waters.

One more definition is important in understanding marine reserves:

Definition: *Marine Wilderness = "An area of the sea . . . along with coastal land where appropriate, that has been protected to preserve or restore its natural character, condition, vistas, living communities, and habitats for present and future generations to enjoy, experience, explore, and study, but leave unaltered. Ocean wilderness areas are large, generally at least 100 square miles, closed to all extractive activities, including all forms of fishing, and to other damaging human activities as needed to ensure the natural communities within flourish, as much as possible unaffected by human activities."* (The Ocean Conservancy 2001)

The concept of marine wilderness has been discussed for at least four decades, following passage of the U.S. Wilderness Act of 1964. The intensity of that conversation has increased greatly in recent years due to recognition of the profound alteration of marine ecosystems discussed briefly earlier in this chapter and detailed in later ones. Nonetheless, progress in protecting ocean wilderness remains slow. The preceding definition, adopted by The Ocean Conservancy in 2001, is similar to that currently under consideration by a broader consortium of conservation interests. Though consistent with and similar to the marine reserve definition provided earlier here, it builds on and expands it in several ways. The most critical differences are that it suggests a minimum size, explicitly states as a goal preserving or restoring the natural character, and raises the bar of protection with respect to other human activities.

EVOLUTION OF TERRESTRIAL AND MARINE PROTECTED AREAS AND CONSERVATION ETHICS

> Imagine that within a national park one of the large carnivores, say wolves, were allowed to be hunted and killed. Or, if not, chased until exhausted and then released. . . . Yet this situation is the status quo for freshwater and marine fish [even] within our national parks. . . . The ordainment of fishing but not hunting indicates an unjustified dichotomy between aquatic and terrestrial species and ecosystems. The results of this . . . management . . . may be causing a[n] . . . erosion of . . . park . . . resources. Research suggests that . . . fish, particularly top predators, play important ecological roles within aquatic ecosystems. . . . In coral reef ecosystems . . . urchins are controlled by a few edible triggerfish and changes in these top predators can have unexpected consequences that can affect the entire ecosystem. (McClanahan, *Bioscience,* 1990)

A little over a century ago, under the leadership of President Teddy Roosevelt and others, the United States began to safeguard great pieces of America's landscape as national parks and wildlife refuges and to espouse a national conservation ethic. Without their great foresight, Yellowstone, Yosemite, and the other great terrestrial landmarks that are part of our national legacy might not exist. Nor would they be safeguarded today had we simply drawn lines on a map back then and failed to develop a stronger terrestrial conservation ethic, invest in their future, or strengthen their protection. The resulting extensive and diverse system of U.S. terrestrial protected areas has served to protect a part of America's natural heritage and to provide a model, which other nations have modified to protect their own natural landscapes. The first of these, Yellowstone National Park, was created in 1872, just about the time the U.S. Fish

Commission was making its observations about the decline of ocean resources generally and the disappearance of fish off the New England coast specifically.

In 1966, nearly a century later, another distinguished group of scientists raised remarkably similar concerns to President Johnson in Effective Use of the Sea, Report of the Panel on Oceanography, President's Science Advisory Committee. They recognized that (1) the near-shore environment was critically important; (2) it was undergoing rapid modification due to human activity, the details of which were unknown, but were broadly undesirable; and (3) this problem was urgent and its dangers had not been adequately recognized (The White House 1966). Among the report's major recommendations to meet its long-range goals of increasing marine food resources and preserving the near-shore environment was the establishment of a national system of marine wilderness preserves and the extension to marine environments of the basic principles and policies of the Wilderness Act of 1964 (Public Law 88-577) to secure for the American people of present and future generations the benefits of an enduring resource of wilderness. Specific purposes identified for such a system included (1) provision of ecological baselines against which to compare modified areas, (2) preservation of major types of unmodified habitats for research and education in marine sciences, and (3) provision of continuing opportunities for marine wilderness recreation.

Diverse national systems of MPAs generally and marine reserves specifically offer tremendous potential to protect our marine legacy and save, study, and sustainably utilize the world's marine biological diversity. Despite this potential, the development of MPAs, their conceptual framework, and the underlying ocean conservation ethic necessary to support them have trailed their terrestrial counterparts by nearly a century. The dumping of nerve gas off Florida and the Santa Barbara oil spill triggered public outrage that contributed to congressional consideration of eleven bills in 1968 to establish sanctuaries and oil drilling moratoria off the coasts of California, Massachusetts, and New Hampshire (CNA 1977). In 1970, a report from the President's Council on Environmental Quality (CEQ) rekindled interest in ocean dumping and sanctuary legislation. In 1972, exactly one hundred years after Yellowstone was created as the country's first national park, the U.S. Congress recognized the lag in development of MPAs, finding that "this Nation has recognized the importance of protecting special areas of its public domain, but these efforts have been directed almost exclusively to land areas above the high water mark." As a result, Congress created the National Marine Sanctuary (NMS) Program to "identify areas of the marine environment of special national significance due to their resource or human-use values" and "provide authority for comprehensive and coordinated conservation and management of these areas" consistent with "the primary purpose of resource protection" (NMSA 2000).

A couple of years into this new millennium, our U.S. MPAs remain near where our terrestrial ones stood at the start of the last century. We have begun to identify and designate some of the cornerstone marine landmarks, areas like the Florida Keys, Monterey Bay, and the Northwestern Hawaiian Islands, as worthy of national marine sanctuary or similar protected status, but we have not yet developed strong enough management plans for them or properly invested in their future, and there remain geographic holes in the system that require filling. To date, less than 1 percent of U.S. marine waters have received national marine sanctuary or similar MPA status, and less than 1 percent of national marine sanctuary waters have received stronger protection as marine no-take reserves (The Ocean Conservancy 2002). McCardle (1997) calculated that the State of California, with over 100 MPAs, fully protects less than .2 percent of its waters from all fishing activities, as marine no-take reserves, and provides effective enforcement for only a fraction of these areas. Similarly, as of 1997, 72 out of Canada's 110 MPAs provided no protection to either marine species or habitats. North America is far from unique with respect to this paucity of strong protection for marine areas. Rather, this condition with relatively few MPAs, comprising a limited area, and affording little protection even where they do exist "characterizes the situation worldwide, in countries rich and poor, in waters warm and cold" (Fig. 1.7); (Roberts and Hawkins 2000).

> As humanity increases its influence on the world's environment . . . marine ecosystems are experiencing pressures that will soon equal terrestrial counterparts. One of the future roles of our parks will be to maintain pristine ecosystems that can be compared to other managed and mismanaged ecosystems. This preservation will be difficult with the parks' many external influences, but will be impossible if internal management allows recreation and resource use to supercede preservation. The subjectivity of the fishing–hunting dichotomy must be relinquished to a more objective management plan that preserves aquatic in the same manner as terrestrial species. (McClanahan 1990)

Since at least the late 1800s, the United States has clearly been a global leader in the effort to conserve terrestrial areas through parks and protected areas. Though far from perfect, the United States together with much of the world has developed a system of terrestrial managed areas that includes a full spectrum of protection levels. The IUCN provides a classification system de-

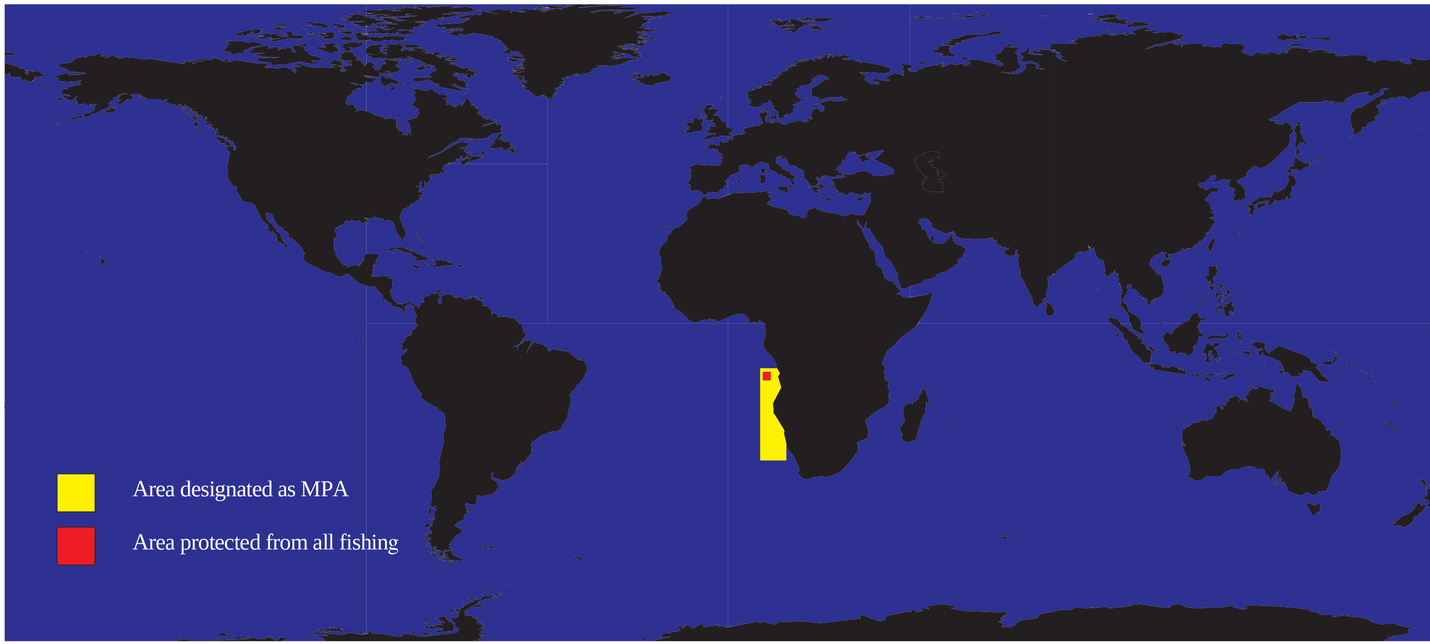

FIG. 1.7 Fraction of Ocean Protected as Marine Reserves and Marine Protected Areas (MPAs). This map shows the small portion of the ocean included in marine protected areas of any type, < 0.5%, and the even smaller portion included in marine reserves protected from all forms of fishing, < 0.0001 percent. The majority of existing MPAs are not yet adequately managed. Source: Figure courtesy of Callum Roberts and Julie Hawkins, adapted from Roberts and Hawkins (2000).

scribing a full range of protected areas applicable to both marine and terrestrial areas (Box 1.1) plus some other public managed area categories not considered to be protected areas under the IUCN system. Collectively, this diverse set of terrestrial protected and managed areas, with variable levels of protection, contributes greatly to conserving the world's biodiversity. There is no similar comprehensive system of MPAs yet in place to protect our marine biodiversity. Some MPAs do exist and make a contribution, but they cover a much smaller portion of the marine environment than terrestrial areas, are greatly skewed to the less protected end, are often poorly funded and weakly implemented, and consequently provide far less protection. The range of MPAs is truncated, with IUCN categories 1 and 2 (Box 1.1) nearly completely lopped off. Neither the United States nor the world has done well in this regard. Unlike the terrestrial case, the United States has not provided strong global leadership on this and, if anything, has probably learned much from other countries, especially island and other nations with extensive coastlines, which have more clearly recognized the value of their coastal assets.

In the mid 1900s, Aldo Leopold recognized the need for humanity to develop a land ethic to advance terrestrial conservation. If he were still alive today, he might argue that this is still lacking and we are still losing the war, but on the terrestrial side some progress has clearly been made and some battles have been won. Today, development of a similar "ocean ethic" must go hand-in-hand with advancing ocean conservation and marine no-take reserves. Some reserve opponents cast their argument from a right to fish perspective. The appropriate question to ask is not, To fish or not to fish? but rather, Must we fish everywhere? On land, we have already decided that hunting should not occur everywhere. Science strongly supports the immediate need for a similar ocean ethic and a societal decision that fishing should not occur everywhere, if we want to stem the tide of changes described in chapters 1–3 of this book, protect ocean ecosystems and species, and halt or prevent the loss of marine biodiversity. However, society, not science alone, will ultimately need to decide whether or not these are things we want to do.

> The last word in ignorance is the man who says of an animal or plant: "What good is it?" If the land mechanism as a whole is good, then every part is good, whether we understand it or not. If the biota in the course of eons, has built something we like but do not understand, then who but a fool would discard seemingly useless parts? To keep every cog and wheel is the first precaution of intelligent tinkering. (Leopold 1953, 146–147)

Box 1.1 IUCN Categories of Protected Areas

Category	Purpose
Ia	**Strict nature reserve/wilderness protection area:** managed mainly for science or wilderness protection—an area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features, and/or species, available primarily for scientific research and/or environmental monitoring
Ib	**Wilderness area:** protected area managed mainly for wilderness protection—large area of unmodified or slightly modified land and/or sea, retaining its natural characteristics and influence, without permanent or significant habitation, which is protected and managed to preserve its natural condition
II	**National park:** protected area managed mainly for ecosystem protection and recreation—natural area of land and/or sea designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations, (b) exclude exploitation or occupation inimical to the purposes of designation of the area, and (c) provide a foundation for spiritual, scientific, educational, recreational, and visitor opportunities, all of which must be environmentally and culturally compatible
III	**Natural monument:** protected area managed mainly for conservation of specific natural features—area containing specific natural or natural/cultural feature(s) of outstanding or unique value because of their inherent rarity, representativeness, or aesthetic qualities or cultural significance
IV	**Habitat/species management area:** protected area managed mainly for conservation through management intervention—area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats to meet the requirements of specific species
V	**Protected landscape/seascape:** protected area managed mainly for landscape/seascape conservation or recreation—area of land, with coast or sea as appropriate, where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, ecological, and/or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance, and evolution of such an area.
VI	**Managed resource protected area:** protected area managed mainly for the sustainable use of natural resources—area containing predominantly unmodified natural systems, managed to ensure long-term protection and maintenance of biological diversity, while also providing a sustainable flow of natural products and services to meet community needs.

Cardiff University and IUCN 2002 Speaking a Common Language Information sheet #3. July 2002. Available online: http://www.cardiff.ac.uk/cplan/sacl.

The visionary conservationist Aldo Leopold penned these words, his "first principle of conservation," in an essay entitled Conservation, driven by the vast destruction and degradation of terrestrial and freshwater ecosystems he observed prior to the mid-1900s. A half century later, as we increasingly recognize and document similar catastrophic changes to marine systems (e.g., Jackson et al. 2001; NRC 1995), it is clear that these and other concepts he developed back then apply equally well to marine systems now.

Particularly worthy of extension to the marine environment is his recognition, fifty years before the term *biocomplexity* was coined, that the outstanding scientific discovery of the twentieth century was not a technical device, such as a television, radio, or, by extension, a computer, space station, or submarine, but rather the complexity of living organisms, their interactions, and their interdependencies. Similarly, his recognition that only those who know the most about these organisms and their relationships can also fully appreciate how little we know about them, and why our aim must be to preserve all of the parts and connections, even though the best scientist cannot recognize all of them, remains as applicable, if not more so, for marine systems than for terrestrial ones. Furthermore, his writings and the examples he provided clearly recognized the need to protect entire ecosystems and retain their integrity, even though his "land ethic" predated the terms *ecosystem management* and *ecological integrity,* let alone their application to the marine realm (Leopold 1953).

CONCLUSION: URGENT NEED FOR NEW APPROACHES, INCLUDING MARINE RESERVE NETWORKS

> The world we have created today as a result of our thinking thus far has problems which cannot be solved by thinking the way we thought when we created them.
>
> —Albert Einstein

New ways of thinking and acting, changes to the status quo, and rapid action are urgently needed to restore some of what's been lost, hold on to some of what's left, protect our options, understand our choices, improve our decisions, and preserve some of the oceans' wilderness for current and future generations to enjoy. A more precautionary, ecosystem-based approach is necessary to do so. As Leopold suggested, we can't afford to lose the pieces. Marine reserves, areas in which all marine life is protected from all forms of fishing and other extraction, and the subject of this book, provide a safety net for them and are an essential part of such an approach, but not the whole answer. Nearly every scientific and government study, report, and reference discussed in this opening chapter and many elsewhere reached this same conclusion.

Chapters 2 and 3 focus more closely on the state of marine ecosystems and fisheries, the impacts of fishing on all levels of biodiversity, and why marine reserves are needed to address some of these impacts. Chapter 4 develops the marine reserve concept more fully and describes what they can do that others tools can't. It also explores the scientific underpinnings of marine reserves, including some of the existing evidence for their efficacy with respect to these. Chapter 5 lays out critical marine reserve design issues and approaches. Chapter 6 examines the equally important human dimensions of reserves. Chapter 7 explores some of the current priorities in scientific and research issues related to reserves and some of the traditional as well as exciting new tools for addressing these. The second part of the book, chapters 8 through 11, tours and reviews the global experience with marine reserves, extracting specific points from a host of sites and providing more detailed case studies for a smaller number. The final chapter also draws on the entire book to provide conclusions and recommendations regarding the use of marine reserves.

REFERENCES

Barkai, A., and C. McQuaid. 1988. Predator–prey role reversal in a marine benthic ecosystem. *Science* 247 (4875):62–64.

Blonder, B. I., J. H. Hunt, D. Forcucci, and W. G. Lyons. 1988. Effects of recreational and commercial fishing on spiny lobster abundance at Looe Key National Marine Sanctuary. In *Proceedings of the 41st Annual Meeting of the Gulf and Caribbean Fisheries Institute,* Charleston, SC: GCFI, 487–491.

Brooks, W. K. 1996. *The Oyster.* Baltimore, MD: Johns Hopkins University Press.

Carless, J. 2001. Ocean exploration: Unlocking the mysteries of the deep to protect the future. *Blue Planet Quarterly* 1(2):18–25.

Center for Natural Areas (CNA). 1977. *Assessment of the Need for a National Marine Sanctuary Program.* Washington, DC: Office of Coastal Zone Management (OCZM). CNA/OCZM 7-35118.

Coleman, F. C., et al. 2000. Long-lived reef fishes: The grouper–snapper complex (AFS policy statement). *Fisheries* 25(3):14–20.

Committee on the Status of Endangered Wildlife in Canada (COSEWIC). 2002. *Canadian Species at Risk*. Ottawa, ON: Canadian Wildlife Service, Environment Canada.

———. 2003. *Canadian Species at Risk*. Ottawa, ON: Canadian Wildlife Service, Environment Canada.

Davis, G. E. 1977. Effects of a Recreational Harvest on a Spiny Lobster, *Panulirus argus,* Population. *Bulletin of Marine Science,* 27(2):233–236.

Davis, G. E., P. L. Haaker, and D. V. Richards. 1996. Status and trends of white abalone at the California Channel Islands. *Transactions of the American Fisheries Society* 125:42–48.

Eggleston, D. B. and C. P. Dahlgren. 2001. Distribution and abundance of Caribbean spiny lobsters in the Key West National Wildlife Refuge: relationship to habitat features and impact of an intensive recreational fishery. *The Journal of Marine and Freshwater Research,* 52: 1567–1576.

Hunt, J. H. 1994. Status of the fishery for *Panulirus argus* in Florida. In *Spiny Lobster Management,* 144–157. Cambridge, UK: Blackwell Scientific.

Huxley, T. H. 1883. Inaugural Address Fisheries Exhibition, London. In *The Fisheries Exhibition Literature,* 1–11. London, 1885.

International Union for Conservation of Nature and Natural Resources (IUCN). 1994. *Guidelines for Protected Area Management Categories.* Gland, Switzerland: Commission on National Parks and Protected Areas.

Jackson, J. B. C. 1997. Reefs since Columbus. *Coral Reefs* 16:23–32.

Jackson, J. B. C., et al. 2001. Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293(27 July):629–637.

Kay, J. J., and H. Regier. 1999. Uncertainty, complexity, and ecological integrity: Insights from an ecosystem approach. In *Implementing Ecological Integrity: Restoring Regional and Global Environmental and Human Health,*121–156. NATO.

Kelleher, G. 1999. *Guidelines for Marine Protected Areas.* Gland, Switzerland and Cambridge, UK: IUCN.

Leopold, A. 1953. Round River. In *The Journals of Aldo Leopold.* New York: Oxford University Press.

Lipcius, R. N., and J. S. Cobb. 1994. Introduction: Ecology and fishery biology of spiny lobsters. In *Spiny Lobster Management,* 1–24. Cambridge, UK: Blackwell Scientific.

Ludwig, D., R. Hilborn, and C. Walters. 1993. Uncertainty, resource exploitation, and conservation. *Science* 260:17–18.

McArdle, D. A., ed. 1997. *California Marine Protected Areas.* La Jolla: California Sea Grant College System.

McClanahan, T. R. 1990. Are conservationists fish bigots? *Bioscience* 40(1):2.

Mead, J. G., and E. D. Mitchell. 1984. *Atlantic Gray Whales. The Gray Whale,* Eschrichtius robustus. Orlando, FL: Academic Press, 33–53.

Myers, R. A., and B. Worm. 2003. Rapid worldwide depletion of predatory fish communities. *Nature* 423(15 May):280–283.

National Marine Fisheries Service (NMFS). 1990. *Historic Fishery Statistics Atlantic and Gulf States 1879–1989.* Silver Spring, MD: NMFS.

———. 2002. Commercial Fisheries and Marine Recreational Fisheries Statistics Survey. Available online: http://www.st.nmfs.gov/st1/ (last accessed Dec. 2003). (NMFS Fisheries Statistics and Economics Web site).

———. 2003. *Endangered and Threatened Species: Final Endangered Status for a Distinct Population Segment of Smalltooth Sawfish* (Pristis pectinata) in the U.S. Federal Register 68: 15674–15680, Washington, D.C.

Norse, E. A. 1993. *Global Marine Biological Diversity: A Strategy for Building Conservation into Decision-Making.* Washington, DC: Island Press.

National Research Council (NRC). 1995. *Understanding Marine Biodiversity: A Research Agenda for the Nation.* Washington, DC: National Academy.

National Science Foundation (NSF). 2001. Biocomplexity in the environment. Available online: http://www.nsf.gov/geo/ere/ereweb/index.cfm.

Pogonoski, J. J., D. A. Pollard, and J. R. Paxton. 2002. *Conservation Overview and Action Plan for Australian Threatened and Potentially Threatened Marine and Estuarine Fishes*. Canberra: Environment Australia.

Roberts, C. M., and J. P. Hawkins. 1999. Extinction risk in the sea. *Trends in Ecology and Evolution* 14:241–246.

———. 2000. *Fully Protected Marine Reserves: A Guide*. Washington, DC: World Wildlife Fund Endangered Seas Campaign.

Rose, C. D., W. C. Sharp, W. J. Kenworthy, J. H. Hunt, W. G. Lyons, E. J. Prager, J. F. Valentine, M. O. Hall, P. E. Whitfield, and J. W. Fourqueran. 1999. Overgrazing of a large sea grass bed by the sea urchin, *Lytechinus variegatus,* in outer Florida Bay. *Marine Ecological Progress Series* 190:211–222.

Sadovy, Y., and A. M. Eklund. 1999. *Synopsis of Biological Information on* Epinephelus striatus *(Bloch, 1972), the Nassau grouper, and* E. itajara *(Lichtenstein, 1822) the jewfish*. Washington, DC: U.S. Dept. of Commerce.

Sharp, W. C. 2000. *Destructive Urchin Grazing in a Sea grass Bed in Western Florida Bay: When Should Resource Managers Intervene?* Key West, FL: The Nature Conservancy.

Tegner, M. J., and L. A. Levin. 1983. Spiny lobsters and sea urchins: Analysis of a predator–prey interaction. *Journal of Experimental Marine Biology and Ecology* 73:125–150.

Tegner, M. J., L. V. Basch, and P. K. Dayton. 1996. Near extinction of an exploited marine invertebrate. *Trends in Ecology and Evolution* 11:278–280.

The Ocean Conservancy (TOC). 2001. *Marine Wilderness Campaign Launch Press Materials*. Washington, DC: The Ocean Conservancy.

———. 2002. *Health of the Oceans 2002 Report*. Washington, DC: The Ocean Conservancy.

United States Commission of Fish and Fisheries. 1880. *Report of the Commissioner of Fish and Fisheries for 1878*. Washington, DC: Government Printing Office.

The White House. 1966. *Effective Use of the Sea: Report of the Panel on Oceanography, President's Science Advisory Committee*. Washington, DC: The White House.

———. 2000. Executive Order 13158 of May 26, 2000: Marine Protected Areas. Federal Register vol. 65, No. 105 Wednesday, May 31, 2000, Presidential Documents, P34909–34911.