Coastal-Marine Conservation:

Science and Policy

G. Carleton Ray *and* **Jerry McCormick-Ray**

Both from
Department of Environmental Sciences
University of Virginia
Charlottesville
Virginia
USA

Illustrations by Robert L. Smith

Blackwell
Publishing

COASTAL-MARINE CONSERVATION: SCIENCE AND POLICY

To Sally Lyons Brown
for her vision
and support

Slow down. . . .
You may be going the wrong way!

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Preface

We have reached a point in history when biological knowledge is the sine qua non for a viable human future . . . A critical subset of society will have to understand the nature of life, the interaction of living creatures with their environment, and the strengths and limitations of the data and procedures of science itself. The acquisition of biological knowledge, so long a luxury except for those concerned with agriculture and the health sciences, has now become a necessity for all.

John A. Moore (1993)

Science is built up with facts, as a house is with stones. But a collection of facts is no more a science than a heap of stones is a house.

Jules Henri Poincaré, *La Science et L'Hypothèse* (1908)

We are at a time in history when science allows us better to understand our global environment, and when human societies clearly recognize the urgency of coastal-marine conservation and the need for sustainable use of resources. During the past century, humans have entered the sea in an era of the "Marine Revolution," acquiring the ability to intrude, exploit, and understand the last, previously unavailable portion of Earth – the oceans (Ray 1970). The rates and magnitude of change brought on by this Revolution follows 5–10 000 years of the Agricultural Revolution and two centuries of the Industrial Revolution. Observation of the quickening pace of change and the way that humans behave and manage themselves, and increasing knowledge of the way coastal and marine ecosystems function, have made apparent major ecosystem instabilities and incongruencies. Confronting these lies at the heart of conservation.

"Conservation," as defined in *Webster's Third New International Dictionary*, is the "deliberate, planned, or thoughtful preserving, guarding, or protecting." It is "planned management of a natural resource to prevent exploitation, destruction, or neglect." It is also "the wise utilization of a natural product," or "a field of knowledge concerned with coordination and plans for the practical application of data from ecology, limnology, pedology, or other sciences that are significant to preservation of natural resources." These definitions presume a working understanding of natural-resource science and illustrate that conservation is an issue-directed activity towards which science can provide guides for informed decision-making at all levels.

This book calls attention to the coastal realm as an ecosystem of global significance, where conservation science plays a fundamental role. This realm is a heterogeneous, extraordinarily complex, biologically diverse portion of Earth where the majority of humanity lives and conservation challenges are among the most urgent (Box P.1). This realm is also distinguished by fragmented jurisdictions, wherein no single agency has sole power to manage, conserve, or protect wide-ranging species or region-scale ecosystems. Many coastal-realm ecosystems are highly perturbed and have been altered into regimes not easily reversed. Often, environmental degradation is perpetuated by attitudes entrained into

Box P.1 Coastal-realm attributes

- Occupies 18% of Earth's surface, 8% of ocean surface, and less than 0.5% of ocean volume
- Provides up to 50% of global denitrification, 80% of global organic matter burial, 90% of global sedimentary mineralization, 75–90% of the global sink of suspended river load and associated elements and pollutants, and in excess of 50% of present-day global carbonate deposition
- Supplies approximately a quarter of global primary production, around 14% of global ocean production, and approximately 90% of world fish catch
- Hosts 60% of the world's people and two-thirds of the world's cities of more than 1.6 million people

Sources: From Holligan & Reiners (1992); Pernetta & Milliman (1995).

social practices and public policies, which assume the following: depleted resources and disturbed ecosystems will automatically recover if left alone: the size of the conservation budget is directly related to conservation effectiveness; conservation is a social science in which the people are managed, not ecosystems; legal mandates for resource protection result automatically, almost by fiat, from scientific information; and science is too uncertain and contradictory to guide conservation – that is, "action" is urgent and information can wait. These assumptions and the accelerating impact of human activities on the coastal realm force consideration of new ways of thinking and of applying conservation tools and practices, which demands an attempt to integrate human life styles and ecosystem behavior, and *vice versa*. History shows that unguided action lacking a scientific basis often leads to undesirable outcomes, and that without scientific information conservation action can lose direction. Conservation thus seeks better-informed, science-based and socially understood policies that can bring necessary changes into force before coastal ecosystems are propelled further into environmental debts from which recovery is difficult and expensive.

This book attempts to draw the reader into thinking about coastal-realm issues and conservation tools, and of linkages between conservation science and policy. Section I reviews the issues and tools for conservation; two chapters document the phenomena that concern conservationists directly, and the plethora of laws, regulations, agreements, organizations, and procedures that have been adopted to halt or minimize many of the effects. Section II provides the science background; its two chapters consider the coastal realm as a global ecosystem and how species' natural history affects and is affected by coastal-realm environments. Section III consists of three case studies: three regional examples, the temperate Chesapeake Bay, the sub-arctic Bering Sea, and the tropical Bahamas. A conservation issue is highlighted for each case study in the context of the region's history, its physical, chemical, and biological attributes, and its present social environment. These "real-world" coastal-realm conservation cases broadly reflect scientific and social-political challenges that are worldwide in scope. Section IV focuses on ecosystem health and conservation challenges; two chapters concern conservation issues in the broader contexts of ecosystem health and change, the environmental debt, and challenges facing coastal-realm conservation. Boxes by contributing authors provide detailed accounts of particular topics in order to amplify the text.

Our approach is not to provide specific answers or solutions to coastal-realm conservation problems. Rather, we attempt to raise discussion, with expectations that readers will explore and debate the many issues, approaches, and solutions that now exist – or that may be deployed in the future. While science can provide guide-posts for better informed decision-making at all levels, society as a whole needs to recognize ecosystem functions and the roles biota play, which together perpetuate ecosystem health, resource sustainability, and human wellbeing. As a result, we hope that future agents of conservation – students, conservationists, managers, policy-makers, legislators, and the concerned public – will be better prepared to tackle the difficult field of coastal-realm conservation.

References, scientific terms, Latin names, and units. This book provides readers with a window into a massive literature on conservation science and policy, including historical literature that provides a context for understanding the present state of knowledge of the coastal realm, its life, and its conservation and management. In-text citations are minimal because most subject material requires extensive references that would make the text cumbersome to read. The reference section at the end of the book is limited to these in-text citations and some suggested readings that can provide a guide to source material. We leave to readers the task of literature research to advance their own interest in particular topics, many of which are continually in the forefront of change. A complete list of references used during the writing of this book is given on the Blackwell Publishing website: <http://www.blackwellpublishing.com/ray/references.pdf>

The language of science is enormous and similar terms may have different, even contradictory, meanings among disciplines. We have attempted to minimize scientific terms by defining some of them in the text. Readers are referred to science dictionaries for other terminology. We use the International System of Units (SI units) and metric measurements (e.g., mt for tonnes) throughout the text, and refer readers to summary reference works on these units for definitions, measurements, and conversions. Exceptions occur when we wish to maintain the original works (e.g. Table 1.6).

Species are referred to by their vernacular ("common") names (herring, blue crab, etc.), with Latin names for identification. Most vernacular names are not standardized (birds and some fishes are exceptions). For example, "cod" is a common name for a valuable Atlantic fish of the cod family (Gadidae), but "cod" in Australia refers to groupers of the sea bass family (Serranidae); similarly, "rockfish" may refer to a number of fishes from a half dozen families of fishes. Therefore, scientific names are essential for identification, and are given with the vernacular the first time the species is mentioned in each chapter, or if far separated.

G. Carleton Ray and Jerry McCormick-Ray

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Section I

Issues and mechanisms

A football-sized jellyfish (*Periphylla* spp.) under antarctic sea ice. McMurdo Sound, Southern Ocean. Photograph by the authors.

The two chapters in this Section document the many issues facing conservation and the many tools for dealing with them. Conservation issues relate specifically to biological issues (i.e., species depletions or habitat change), to issues that involve human activities (i.e., resource extractions and pollution), or to less apparent issues that affect ecosystem structure, function, and resiliency. Together these issues result in environmental change that is increasing in rate, magnitude, and duration, and from which recovery is difficult. Collectively, these issues contribute to an environmental debt, which is the total adjustment required to recover from change. The many current conservation and management mechanisms now in use overwhelmingly direct methods towards resolving specific issues, one by one. Although many successes are apparent, the environmental debt looms ever greater. Therefore, how can conservation mechanisms be made more effective to deal with the critical individual issues while confronting the mounting environmental debt?

Top: A healthy, high-diversity reef with corals, sponges, and gorgonians, Exuma Cays, Bahamas. Bottom: Turtlegrass (*Thalassia testudinum*) bed with a common sea star (*Oreaster reticulatus*) Cay Sal Bank, Bahamas. Photographs by the authors.

Chapter 1

Conservation issues

The materials of wealth are in the earth, on the seas, and in their natural and unaided productions.
Daniel Webster

It is time to understand "the environment" for what it is: the *national-security issue of the early twenty-first century.*
Robert D. Kaplan

1.1 Introduction

Three sets of issues compel recognition of forces that are global in scope, deepen the environmental debt, and raise ethical concerns about sustainability. Primary issues focus on species and their habitats and have long been the major focus of conservation. Secondary issues, conversely, direct attention toward human activities as causes for change. These activities have only relatively recently received conservation attention. However, the accelerating rates and momentum of human activities, and consequent ecosystem changes, have become high conservation priorities.

Efforts to address primary and secondary issues have slowed the depletion of life and its habitats, but have mostly failed to reverse trends of depletion and loss. This situation requires attention to systemic tertiary issues, involving emergent environmental phenomena, altered ecosystem states, and rates and dimensions of environmental and social change. Tertiary issues cause coastal-marine conservation to face complex, chronic problems that confound simple solutions.

1.2 Primary issues

Historically, most emphasis has been placed on depletion and extinction of species and protection of habitat. Yet, primary issues expand these domains to include species overabundance, ill-health, abnormal behaviors, and deteriorating habitats. Together, primary issues bring public attention to the need for conservation action.

1.2.1 Species extinction and depletion

Extinctions and depletions of coastal-marine species are documented worldwide and across most taxa (Table 1.1). Of the more than 120 species of marine mammals, at least a quarter is presently depleted and several are extinct. The Atlantic gray whale probably became extinct during the earliest days of Native American and European whaling. The Steller sea-cow population had probably already been decimated by subsistence hunters when it was discovered in 1741, and was hunted to extinction only 27 years later. The four remaining sea cows (one dugong and three manatees) are all endangered. The Caribbean monk seal was last reliably sighted in the 1950s near Jamaica. The Mediterranean monk seal population hovers around 300–400 individuals and the Hawaiian monk seal is also endangered. Large baleen whales seemed to be on the road to extinction until almost all whaling ceased in the 1980s; the North Atlantic right whale remains at risk. The Chinese river dolphin is critically endangered, as is the vaquita, a small porpoise endemic to the northeastern Gulf of California; both are among the world's rarest mammals. Sea birds and sea turtles have suffered similar fates. Most sea turtles are endangered. The Labrador duck and the flightless great auk became extinct in the 1800s, due to decimation by hunters for food, and many large sea birds, particularly albatrosses, are still being depleted.

Invertebrates and fishes are difficult to observe. The first documented extinction of a marine invertebrate was the North Atlantic eelgrass limpet, which disappeared in the early 1930s when a disease exterminated eelgrass beds, its sole habitat. The California white abalone existed in the thousands in the 1960s; now, the few remaining individuals are so widely separated that they may not be able to reproduce. Lately, fishes have elicited great public concern. Once abundant populations of cod, haddock, swordfish, salmons, tunas, sharks, and others have become severely depleted. The barndoor skate of the northwest Atlantic has been

Table 1.1 Selected extinct, endangered, and depleted species, illustrating worldwide depletion and extinction among a wide range of species groups.

Common name	Latin name	Range
Invertebrates		
Eelgrass limpet	*Lottia alveus*	North Atlantic
Rocky, mid-intertidal limpet	*"Collissella" edmitchell*	California (USA)
White abalone	*Haliotis sorenseni*	California (USA)
Fish		
Shortnose sturgeon	*Acipenser brevirostrum*	North Atlantic
Chinook salmon	*Oncorhynchus tshawytscha*	North Pacific
Totoaba (sea trout)	*Cynoscion macdonaldi*	Gulf of California
Barndoor skate	*Diptura laevis*	North Atlantic
Reptiles		
Green turtle	*Chelonia mydas*	Worldwide
Kemp's Ridley turtle	*Lepidochelys kempii*	Gulf of Mexico
Birds		
Auckland Island merganser	*Mergus australis*	New Zealand
Tahitian sandpiper	*Prosobonia leucoptera*	French Polynesia
New Providence hummingbird	*Chlorostilbon bracei*	Bahamas
Guadalupe storm petrel	*Oceanodroma macrodactyla*	Mexico
Bonin night heron	*Nycticorax caledonicus*	Japan
Steller's spectacled cormorant	*Phalacrocorax persipicillatus*	Komandorskiye Is. (Russia)
Canarian black oyster catcher	*Haematopus meadewaldoi*	Canary Islands (Spain)
Javanese wattled lapwing	*Vanellus macropterus*	Indonesia
Labrador duck	*Camptorhynchus labradorius*	North Atlantic
Great auk	*Pinguinus impennis*	North Atlantic
Short-tailed albatross	*Diomedea albatrus*	North Pacific
Cahow (Bermuda petrel)	*Pterodroma cahow*	North Atlantic
Mammals		
Steller sea cow	*Hydrodamalis gigas*	Komandorskiye Is. (Russia)
Caribbean monk seal	*Monachus tropicalis*	Caribbean Sea
Mediterranean monk seal	*Monachus monachus*	Mediterranean
Hawaiian monk seal	*Monachus schauinslandi*	Hawaiian Islands
Atlantic gray whale	*Eschrichtius robustus*	North Atlantic
Northern right whale	*Balaena glacialis*	North Atlantic
Chinese white flag dolphin	*Lipotes vexillifer*	Yangtze River
Vaquita porpoise	*Phocoena sinus*	Gulf of California
Marine otter	*Lutra felina*	South Pacific
Sea mink	*Mustela macrodon*	Nova Scotia to New England

Compiled from Carlton (1993); Norse (1993); Upton (1992); WCMC (1992).

drastically reduced due to by-catch in nets intended for other species. In the northern Gulf of California, the estuarine totoaba has become threatened by fishing, damming, and massive extraction of water from the Colorado River.

Coastal fishes that ascend or descend rivers and estuaries to spawn are especially vulnerable. Sturgeons, salmons, shad, menhaden, and others are widely depleted. Most sturgeons that inhabit fresh and coastal waters of Europe, Siberia, and North America are listed as threatened or endangered. The European sturgeon is one of the largest and most valuable of all fishes, and was common in the 1800s from the Baltic to the Black Sea. By the 1940s, spawning apparently occurred in only two rivers of western Europe. North American sturgeons have suffered similar fates. Many fishes that return to natal rivers to spawn, notably the "king" of salmons, the chinook, have been depleted or extirpated due to combinations of habitat alteration, pollution, and overfishing.

These few examples exemplify an issue of unknown dimensions. Many species remain to be discovered and many species, especially of smaller size and lesser economic importance, have no doubt disappeared without documentation of their existence. Data on population trends are especially sparse because original population numbers are not known.

1.2.2 Overabundance

Conversely to depletion, many species have recently flourished and become a concern when they dominate their communities, threaten human livelihood, depress densities of other species, deplete their own habitats, or cause a change in ecosystem function (Table 1.2). Overabundance is of greatest concern when native or introduced (exotic) species become invasive and do harm to other species or to their ecosystem. In areas of the Indo-Pacific, the native crown-of-thorns starfish recently became so numerous that it decimated coral reefs. The introduced American comb jelly, *Mnemiopsis*, has reduced plankton biomass and altered food webs of the Black and Azov seas. A fast-growing exotic alga, *Caulerpa*, is transforming portions of the Mediterranean seafloor into a dense, single-species cover, and has recently appeared in southern California and Australia. The invasive, native, common reed now dominates many U.S. wetlands (Box 1.1).

Box 1.1 A perspective on an overabundant invasive species: common reed, *Phragmites australis*

James E. Perry

An "invasive species" is defined as an alien species (i.e., any plant or animal species that is not native to that ecosystem) whose introduction causes, or is likely to cause, economic or environmental harm or harm to human health (U.S. Presidential Executive Order 13112). While the term "native" implies that invasive species come from a foreign country or continent, it is important to note that this is not always the case. Given the dynamic nature of ecosystems and the propensity for humans to modify these habitats (such as filling or dredging of wetlands), we now know that some of our native species will become invasive if given the opportunity. The common reed, *Phragmites australis*, is one of these species. This vascular plant occurs in wetlands throughout the world. It is an aggressive colonizer of disturbed sites and exhibits rapid vegetative propagation (1–2 m yr^{-1}), and is capable of suppressing competitors by shading and litter mat formation, which gives the plant a distinct advantage over other species. Once established in a wetland, it is extremely difficult and expensive to eradicate.

Common reed has become a distinct problem in restored and/or created wetlands in the mid-Atlantic region of the United States. Because of the disturbance nature of wetland restoration and/or construction (earth removal and movement), newly constructed marshes are highly susceptible to common reed invasion. This species is considered undesirable by resource managers of this region partly because of its ability to replace the dominant species of numerous tidal and non-tidal wetland plant communities and, therefore, to reduce habitat diversity. On highway I-95 in New York–New Jersey just south of New York City, hundreds of acres of common reed have replaced a mixed community of salt, salt meadow hay, and tall cordgrass marshes. Common reed has become invasive through its ability to rapidly colonize disturbed, particularly human-disturbed, habitats. Thus, for every road crossing, every dredge-spoil sidecasting, and every parking lot next to a marsh, common reed has invaded into other marsh types, and has lowered the biodiversity of these important systems.

Attempts to limit or eradicate common reed have met with variable success. Small populations can be removed by pulling up plants, but this needs to be done before flowering to avoid dispersing seeds during removal. Application of herbicides can be effective, but care must be taken as these broad-spectrum herbicides can destroy adjacent desirable species. Most current use of herbicides is in conjunction with multiple burnings of the marsh. The financial cost of eradication is high. Herbicides themselves are expensive and spraying of large areas is done by helicopter. Some managers question these costs, particularly when one considers that eradication is usually temporary: in most cases the common reed will return from adjacent wetlands to repopulate the treated area. Salinity and flooding have also been shown to have adverse effects on common reed, and die-back has been reported at sites where soil salinity was higher than 15‰.

The questions common reed poses to wetland scientists, regulators, and managers are complex. Since wetland restoration and/or creation will continue in the mid-Atlantic United States, what role should common reed be allowed to play in future wetland plant communities? Can wetland restoration and/or creation be considered successful if these sites are quickly invaded by common reed?

Table 1.2 Examples of overabundance. Some are natives; others are exotics (E).

Organism/Origin	Location affected	Characteristic	Impact
Dinoflagellates (microflagellate) Worldwide	Coastal seas, worldwide	Red and brown blooms	Discolors water; may kill variety of species; produces shellfish toxins
Chrysophytes (micro-golden algae) Worldwide	Coastal seas, worldwide	Golden-brown blooms	Discolors water; shades aquatic plants; disrupts food webs; causes hypoxia
Diatoms Worldwide	Coastal seas, worldwide	Algal blooms	Sometimes lethal; mucus clogs fishing nets
Cyanobacteria (blue-green algae) Worldwide	Global ocean, coastal	Blue-green algal bloom	Range from harmless to toxic
Green alga *Caulerpa taxifolia* Aquaria	Mediterranean, California, Australia	Invasive macro-alga (E)	Threatens benthic community
Australian "pine" *Casuarina equisetifolia* India to Australia	Tropical islands and coasts, worldwide	Invasive tree on impoverished or disturbed soils (E)	Invasive; alters ecosystems; depletes biodiversity; causes erosion
Jelly *Aurelia aurita* Northwest Atlantic	Black Sea	Pelagic, plankton-feeder (E)	Nuisance; biomass ~450 million tons
American comb jelly *Mnemiopsis leidyi* Northwest Atlantic	Mediterranean, Black, Azov seas	Pelagic carnivore of plankton (E)	Threatens plankton biomass and fisheries
European green crab *Carcinus maenas* Northeast Atlantic	Northern California, Oregon	Voracious benthic invertebrate (E)	Threatens small shore crabs, native clams, near-shore invertebrates
Chinese clam *Potamocorbula* sp. Northwest Pacific	San Francisco, Northern California	Invasive benthic invertebrate (E)	Threatens benthic community
Indo-Pacific mussel *Perna perna* Tropical Pacific	Gulf of Mexico	Invasive filter-feeder (E)	Nuisance; beds extend for kilometers
Zebra mussel *Dreissena polymorpha* Europe	Baltic Sea, North America, Europe	Invasive freshwater filter-feeder (E)	Clogs pipes; eliminates benthic life; reduces plankton abundance
Crown-of-thorns starfish *Acanthaster planci* Indo-Pacific	Indo-Pacific	May suddenly increase in numbers	Consumes coral polyps; decimates reefs
Lionfish *Pterois volitans* Indo-Pacific	Northwest Atlantic	Introduced from aquaria (E)	Highly toxic, voracious carnivore
Snow goose *Chen caerulescens* North America	North American Arctic	Explosive overabundance	Degrades arctic nesting area
Gray seal *Halichoerus grypus* North Atlantic	North Sea	Abundant and protected	Said to deplete cod fisheries
California sea lion *Zalophus californianus* Northeast Pacific	Northeast Pacific	Increasing and protected	Consumes salmons; has become a "pest" on docks

Compiled from Carlton (1985); Duxbury & Duxbury (1997); Kenney et al. (1996); Pollard & Hutchings (1990a,b); NAS (1995); Raloff (1998); Schneider & Heinemann (1996); Sherman et al. (1996); Stephens et al. (1988); Steneck & Carlton (2001); Whitfield et al. (2002); Woodham (1997).

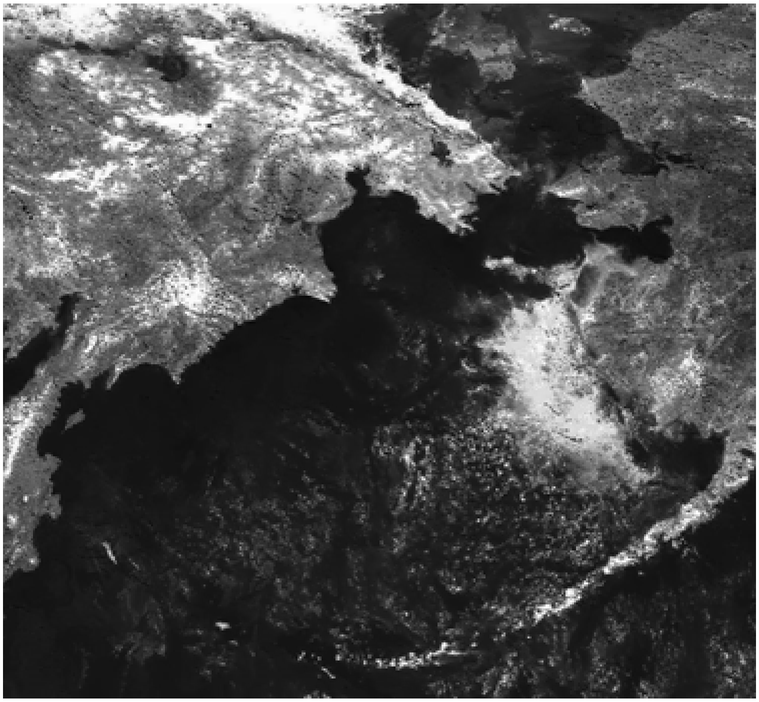

Fig. 1.1 Satellite image of the Bering Sea, September 1998. A plankton (coccolithophore) bloom is the light-shaded area, on right. Causes unknown; no deleterious effects discovered. Courtesy of Jacques Descloitres, NASA Goddard Space Flight Center.

Planktonic species are especially notable invaders, and often "bloom" in such massive numbers that they discolor the water, as "red tides" (dinoflagellates), "green films" (cyanobacteria), and "brown tides" (chrysophytes). Some blooms are localized in bays or estuaries; others cover thousands of square kilometers (Fig. 1.1). Blooms may last for weeks. Some occur at the same time and place each year; others occur unpredictably. Some are harmless; others kill marine life and produce noxious gases. Causes are often obscure; some occur in response to nutrient inputs.

Overabundance also occurs in aquatic birds and mammals. The snow goose has exploded in numbers and is causing extensive habitat damage in coastal breeding areas. Fishermen claim that overabundant seals deplete valuable fisheries: for example, gray seals that consume cod in the North Sea and California sea lions that consume salmons on North America's Pacific coast.

1.2.3 Ill-health

Ill-health focuses on abnormal physiological states and compromised immune systems, expressed as lesions, diseases, and deformities. These have been recorded for a wide variety of taxa, in epidemic proportions, regionwide, associated with pollution, as massive die-offs, or as individual strandings (Table 1.3). Ill-health brings into question what constitutes normalcy. Little is known about the "normal state" of health of most marine species. For example, in corals and their relatives, ill-health is described as "white line," "black line," and fungus diseases of uncertain etiology and taxonomy.

Many diseases are recently discovered. Farmed Atlantic salmon (*Salmo salar*) are susceptible to contagious infectious anemia. A tumor mass (fibropapillomatosis) caused by a virus is commonly observed in sea turtles. A brain disease (avian vacuolar myelinopathy) has inflicted coastal bald eagles and waterfowl in the southeastern United States. And in Scotland's northeast waters, more than 90% of a population of adult bottlenose dolphins (*Tursiops truncatus*) had epidermal lesions.

In polluted harbors and contaminated waters, ill-health takes many forms, including skeletal deformities, tumors, sores, fin rot, pathogenic viruses and bacteria, fungi, protozoans, and various invertebrate parasites. Pollution has also been shown to induce malformation and mortality, associated with abnormal embryonic chromosome division, for example in planktonic eggs

Table 1.3 Examples of ill-health.

Condition	Group(s) affected (Disease)	Location
Orange disease	Coralline algae: *Porolithon*	South Pacific
Abnormalities: shell/spine deformities, abnormal scales	Invertebrates; fishes	North Atlantic, Japan, South California
Moribund Withering Syndrome	Red abalone: *Haliotis*	South California
Lesions: skin, skull, brain, other organs. Pathogens mostly unidentified	Fishes (ulcerations, fin rot), marine mammals, birds	Baltic, North Sea, Southwest Atlantic
Fungal infections	Sea fans *Gorgonia ventalina*; corals, several; seagrass *Zostera marina* (wasting disease); fishes, herrings	North Atlantic, Florida, Central and South America, Caribbean
Tumors	Fishes; sea turtles (fibropapillomatosis)	Bays, harbors, coasts, banks, sounds, estuaries
Viral infections	Fish (lymphocystis) Birds (infectious bursal disease) Seals (phocine distemper) Sea otter *Enhydra lutris* (herpesvirus) Marine mammals (morbillivirus)	Worldwide; Northeast Pacific
Bacterial infections	Corals *Acropora palmata*: "white pox" (*Serratia marcescens*) Fish (hemorrhagic disease, fin rot, ulcerations, red sore)	Industrial-urban bays, harbors, coasts, reefs; Wider Caribbean
Protozoan infections	Oysters (dermo, MSX) Dolphins (fatal hepatic sarcocystosis)	Worldwide
Reproductive disorders	Fishes (defective eggs, larvae) Marine mammals (reproductive failure, aborted fetuses)	Baltic, North Sea, North Atlantic, North Pacific, Arctic

Compiled from Aguirre (1998); Cervino et al. (1998); Geiser et al. (1998); Littler & Littler (1995); Nagelkerken et al. (1997); Patterson et al. (2002); Raloff (1998); Reimer & Lipscomb (1998); Resendes et al. (2002); Sindermann (1996); Wilson et al. (2000).

of Atlantic mackerel (*Scomber scombrus*). Furthermore, some marine diseases are of human origin: a bacterial species of the human gut has recently been shown to be a pathogen of corals.

1.2.4 Abnormal behavior

Changes in distributions and behavior, such as altered times and places of breeding, have been observed in coastal-marine species in response to climate or to human-caused alterations of the land- or seascape. Most altered behaviors have been recorded for birds and mammals that are relatively easy to observe. Some waterfowl that normally feed on shallow-water vegetation now consume crop residues left on farms and may not migrate. Gulls have become nuisances around garbage dumps and fishing vessels. Gulls and sea lions follow fishing boats to feed on discarded offal. California sea lions become noisy nuisances when they haul out on docks. Florida manatees often avoid winter's cold by congregating in warm-water effluents of power plants. Some cetaceans hybridize, but whether this is abnormal is unknown.

Marine mammal strandings are of particular interest (Box 1.2). One cause may be avoidance of unfavorable water conditions, such as toxic algal blooms. Another cause may be noise generated by ships: commercial, recreational, and military uses of the seas all produce significant noise and have rapidly increased in recent years. Strandings almost always arouse great public attention and, nowadays, intense efforts are made to direct the animals back to sea or save them under veterinary care.

Attacks on humans may be abnormal, and causes for shark attack are speculative. Sharks have decreased in numbers recently; yet, shark attacks do not appear to be decreasing, possibly because of increased numbers of swimmers in nearshore waters. Occasional attacks by marine mammals on swimmers suggest responses to human harassment. On the other hand, some marine mammal interactions with humans are mutualistic, positive, and learned. The immortalized killer whale, "Old Tom" of Twofold Bay, Australia, guided Australian whalers to humpback whales in the early 1900s. Tom was rewarded with the tongue of the whale. Dolphins are also known to aid coastal fishermen in pursuit of

Box 1.2 Cetacean strandings

James G. Mead

The word "stranding" is derived from "strand" the shore of the sea. The word usually applies to a denizen of the marine environment that has come ashore, whether under its own volition or not. When whales and dolphins die they normally sink to the bottom. If the water is shallow, decomposition gases form in the tissues and the carcass floats and drifts ashore. In waters that are sufficiently deep, the gases remain in solution and the body decomposes on the bottom.

Single strandings represent individual mortality and are of interest only when they occur in unusual numbers. Mass strandings are events that involve a number of animals. Sometimes stranded animals do not have to be close together to constitute a mass stranding. A case in point is the stranding of short-finned pilot whales (*Globicephala macrorhynchus*) along the east and gulf coasts of the United States. From 1970 to 1980 the number of individuals averaged 1.8 per year (range 0–3). Suddenly, four strandings occurred in May 1973, scattered from Ocean City, New Jersey, to Bodie Island, North Carolina. This may be categorized as one mass stranding, extended in space. Any one of those would be classed as a single stranding, without information on the others. Baleen whales (mysticetes) have not been shown to be subject to the same mass strandings as toothed whales (odontocetes). A 1987–88 mortality of humpbacks, involving 14 individuals during 5 weeks and over about 300 km distance, could have been interpreted as a mass stranding. This event was, however, shown to be the result of paralytic shellfish poisoning.

Mass strandings have been occurring for millennia and have been subjects of speculation for almost as long. However, whether some events referred to in the literature are mass strandings or drive fisheries is problematic. Some of the largest strandings were false killer (*Pseudorca crassidens*) and long-finned pilot (*Globicephala melas*) whales. These strandings occurred in areas and at times when there was an active drive fishery (Japan and Massachusetts, respectively). The highest mortality recorded to date is 310 long-finned pilot whales that stranded in New Zealand in 1987.

Explanations of the causes of mass strandings are: confusion induced by coastal topography along shallow, sloping, sandy shorelines; errors in geomagnetic navigation; reversion to ancient migratory routes; pollution; ingestion of debris; chase or harassment; unusual underwater noises; sudden stress; shallow-water feeding; and diseases, parasites, neurological disorders, suicide, overpopulation, or getting blown ashore by storms. In 1987 and 1988 there was a spectacular increase in strandings of bottlenose dolphins (*Tursiops truncatus*) along the Atlantic coast of the United States. The mortality lasted from June 1987 to February 1988 and extended from New Jersey to Florida. Painstaking work by an army of investigators on those stranded animals determined that the mortality was due to morbillovirus infection.

Strandings provide scientists with an avenue for investigating cetaceans. The most basic information of all, the existence of a species, is frequently brought to light by strandings. Original descriptions of 20 out of 21 species of beaked whales (Family Ziphiidae) have been based on strandings. Strandings also contribute to the gradual assembly of life-history information, including feeding habits, reproduction, age, growth, and pathology. Ideas about the functional mechanisms that cetaceans have evolved may depend on comparative studies – for example, insights into thermoregulation of reproductive tissues. Recognizing pathologies depends on knowledge of the anatomical structure of "normal" animals. Strandings provide a way of monitoring adverse human interactions with cetaceans. Increased mortality due to fisheries interactions is frequently observed on stranded animals, for example subtle net marks. Stranded animals also provide a source of material for monitoring levels of anthropogenic contaminants (pollution) in marine systems.

fish, and reports of dolphins associating with people have become common.

Materials introduced by humans into the sea profoundly alter feeding behavior, for example when objects unfamiliar to sea life are ingested. Sea turtles, sea birds, and marine mammals are especially likely to ingest foreign objects, and each year many thousands may be injured, receive inadequate nutrition, or die because of this propensity. Additionally, sea birds, sea turtles, and large, pelagic fishes take longline fish hooks and many thousands die.

1.2.5 Deteriorating habitats

Interest in habitat extends to valued species, biodiversity, habitats created by living organisms (e.g., living reefs), and ecosystem functions. For thousands of years, coastal wetlands in China have been converted to rice production. In the conterminous United States, more than half of all coastal wetlands are degraded or have been converted. Globally, beds of aquatic vegetation have been decreasing, affecting the abundance of invertebrates and waterfowl. Since the 1960s, more than half of all tropical mangroves have been logged and replaced by croplands, shrimp ponds, and tourist resorts. Also, coral reefs are deteriorating globally as a result of bleaching, disease, and human disturbances. Temperate oyster reefs have been depleted even more intensively and for a longer period; those that remain are now vestiges of their former extents.

On a larger scale, bays, sounds, and estuaries have been dramatically affected by alteration of watershed flows, overfishing, pollution, and human occupation. Many productive coastal habitats are in critical states of deterioration and contamination, particularly in industrialized regions. A case in point is San Francisco Bay: during the past century and a half, approximately 60% of its area has disappeared under a massive sediment load released from upland mining and other forms of development. The Mississippi River has been physically changed by levées since the early 1800s; today, its delta region and the northern Gulf of Mexico are subject to nutrient enrichment, oxygen deficiencies, and depleted food webs. Similar changes have occurred in most of the world's major bays, rivers, and estuarine systems.

Islands and beaches are of special concern. On land, islands have experienced the world's highest extinction rates. Oceanic islands inspired Charles Darwin and Alfred Russel Wallace to formulate the Theory of Evolution in the mid-1800s. Islands are hotbeds of evolution and host a high degree of endemism; 12 m sunflowers, 250 kg tortoises, peculiar creatures such as marine iguanas, and many others occur nowhere else. The world's longest barrier-island/beach system occupies United States coasts from Maine to Texas. Many of its approximately 300 barrier islands are undergoing rapid change, affecting beach-nesting birds and sea turtles and the barriers' ability to protect nearshore environments from ocean forces. Islands are also notorious for the ease with which natural communities can be upset by exotic species and other disturbances. However, very little is known of extinction off island shores.

1.3 Secondary issues

Secondary issues focus on regulation of human activities and resolution of conflicts that are generated as people mass into the coastal realm. These issues draw attention to changes in which humans have, for centuries if not millennia, been foremost agents of alteration.

1.3.1 Extractions: removing natural resources

Human societies have long benefited from seemingly endless supplies of food, minerals, chemicals, industrial products, building materials, and energy extracted from coastal land and oceans. Even seawater is a significant resource, from which freshwater, salt, and power can be extracted. Extractions usually result in ecosystem adjustments.

1.3.1.1 Fisheries

Modern fishing is an analog of the ancient hunter–gatherer. Its history resembles a "slash-and-burn" activity, moving from resource to resource and from ocean to ocean, taking first the largest, most valuable, and easiest species to hunt, then the smallest, most abundant, and logistically more difficult. Commercial fishing is dominated by only a few nations, with Peru, Japan, Chile, China, and the United States being the leaders in terms of tons landed. Today, the number of fishermen worldwide approaches 20 million; 90% are small-scale fishers who may account for 25% of the global catch. Furthermore, the fisheries industry employs almost ten times more persons than fishermen, including processors, shippers, and marketers.

World marine and inland fisheries production trebled from 18 million metric tons (mts) in 1950 to more than 100 million mts by the turn of the century (Fig. 1.2), by which time nearly 70% of the world's

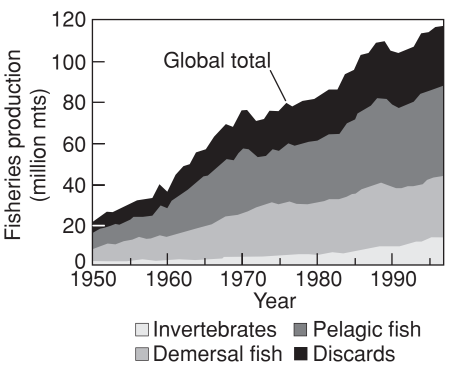

Fig. 1.2 Global fish catch has increased during the past half-century. Increasing catch of pelagic species is due mostly to increased catch of small species, while catch of demersal fish species has stagnated, and by-catch (mostly discarded) has increased. From Pauly et al. (2000), with permission from Sigma Xi.

marine commercial fish populations had become depleted. Today, few areas of the world remain unexploited. About 40% of the total catch enters an expanding market for human consumption. At least 20% is discarded as by-catch of non-target species. The remainder is divided among commercial and industrial uses, including pet food and fertilizer. As demand has increased, competition among fishers and the effort needed to catch a given weight of fish have increased, resulting in collapses of formerly flourishing fish populations. Technology also plays a significant role. Even small fishing vessels are equipped to pinpoint fishing grounds and to find fish. Therefore, despite collapses, new resources have been exploited and total landings have increased.

Whaling illustrates many aspects of commercial fishing. The most abundant and largest species of easiest access in coastal waters were hunted first, then depleted, and discovery of new populations followed. Intensive European whaling began in the 18th century for the right whale (*Eubalaena glacialis*) in the northeast Atlantic, where this species was soon extirpated. Later, New Englanders pursued right whales in the northwest Atlantic. Again, the whales were depleted; only a remnant population now remains, with dubious chances for recovery. In the 1820s, New Englanders took up whaling for sperm whales (*Physeter catodon*) for their valuable oil. At about the same time, bowheads (*Balaena mysticetus*) were pursued in the Bering Sea. Both species soon became depleted. Development of larger ships and better technology allowed whaling to expand to remote areas. The most lucrative whaling followed the late 19th-century development of fast ships equipped with harpoon guns that could navigate high-latitude, nutrient-rich seas where whales aggregated in summer to feed. Whaling soon became a major industry in the Southern Ocean surrounding Antarctica where whalers caught the speedy rorquals (*Balaenoptera* species) and humpbacks (*Megaptera novaeangliae*). Meanwhile, lucrative hunts were underway in other oceans. During World War II, global whaling was interrupted. The post-War period saw the most intensive whaling of all. The result has been that most populations of large whales have been reduced to remnant ones (Fig. 1.3). Today, only the little 6–10 m minke whale (*Balaenoptera acutorostrata*) is legally taken in the Southern Ocean and the North Atlantic.

Fishing reflects a similar history. A typical pattern is observed in the exploitation of temperate, schooling fishes in the North Atlantic. Herring (*Clupea harengus*), Atlantic cod (*Gadus morhua*), and others have supported European societies for many centuries (Fig. 1.4). Widespread depletions began in the 1800s. After World War II, increasing demand drove fisheries industries to exploit fishes more intensively. Depletions occurred first in the east, then in the west, and finally northward.

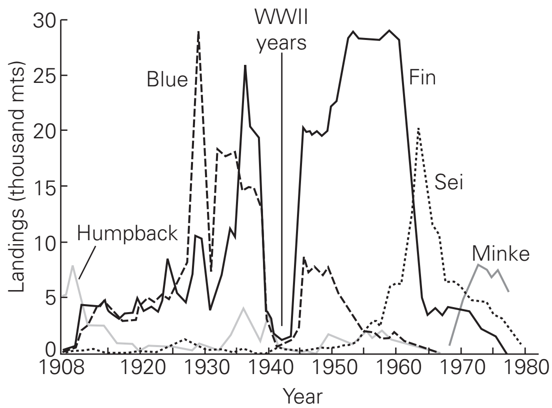

Fig. 1.3 Catch of baleen whales in the Southern Ocean from 1908 to the mid-1980s' moratorium established by the International Whaling Commission. Humpbacks were depleted first, then rorquals, in sequence from largest to smallest. From Jennings et al. (2001), with permission.

Today, fishing vessels are larger and more numerous than ever: in 1998, some 1124 fishing vessels greater than 100 tons were added to Lloyd's records. This increase in the fleet has been accompanied by major improvements in technology. Improvements in fish-finding devices and navigational aids have increased efficiency to the point that few fish schools go undetected. Trawl nets and seines have vastly increased in size, and towing two or more trawls can increase catch efficiency by 50–100%. Longlines with thousands of hooks may extend for tens of kilometers, and high seas drift nets can be more than 2 km long. All of these developments are highly efficient, but are non-selective and can result in greatly increased, unintended by-catch. Purse seines catch mammals and juvenile fish, and longlines and gillnets catch sharks, seabirds, and sea turtles. Furthermore, "ghost fishing" – the capture or entanglement of untargeted fish caught by discarded traps or nets at sea – results in considerable waste. Added to this are growing problems of illegal, unreported, and unregulated fishing that seem to be increasing worldwide. Finally, sport fishing is expanding and goes largely unrecorded, which substantially increases fisheries impacts and introduces uncertainty into management.

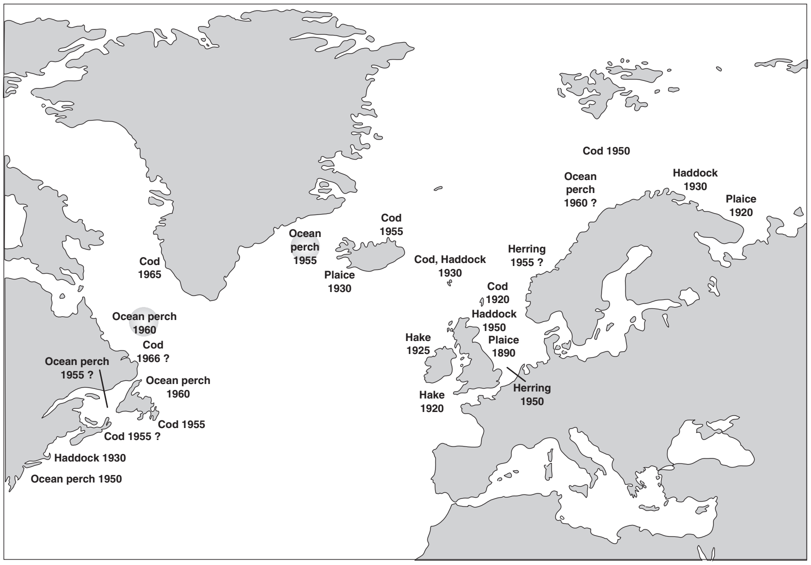

Fig. 1.4 Overfishing in the North Atlantic from before the 20th century. Plaice (*Pleuronectes platessa*) were depleted first in the North Sea; subsequently, fishing shifted to other areas, where the species was also depleted. The same sequence has occurred for other North Atlantic fisheries. Dates indicate approximately when increases in fishing effort no longer produced an increase in catch. From Holt (1969), with permission from Mr. N.H. Prentiss.

Table 1.4 Types of marine mineral resources.

Unconsolidated (within water)			Consolidated (packed, hardened)	
Dissolved	**Surficial**	**In place**	**Surficial**	**In place**
Metals, salts in fresh- and seawater: Magnesium, potassium, sodium, calcium, bromine, sulfur, strontium, boron, uranium, and many other elements	*Shallow beaches; offshore placers*: Sand, gravel; heavy minerals: iron, silica, lime *Deep ocean-floor deposits*: Red clays, calcareous ooze, siliceous ooze, metalliferous ooze *Authigenic deposits*: Manganese nodules (Co, Ni, Cu, Mn), phosphorite nodules, phosphorite sands, glauconite sands	*Buried and in river placers*: Diamonds, gold, platinum, tin *Heavy minerals*: Magnetite, ilmenite, rutile, zircon, leucoxene, monazite, chromite, scheelite, wolframite	*Exposed stratified deposits*: Coal, iron ore, limestone *Authigenic coatings*: Manganese oxide, associated Co, Ni, Cu, phosphorite	*Disseminated massive, vein or tabular deposits*: Coal, iron, tin, gold, sulfur, metallic sulfides, metallic salts

Modified from Mangone (1991).

1.3.1.2 Minerals

The coastal realm is a distinct geological province, where mineral resources of geological and biological origin occur in solution, on the sea-bed surface, or buried (Table 1.4). Salt, magnesium, and bromine are recovered from seawater. Rock, coral, calcareous marls, shells, sand, gravel, and lime are commonly removed from coastal areas. Mining of phosphorite for fertilizer often results in stripping salt marshes. Tin is taken from alluvial deposits on shores or beaches in Malaysia, Indonesia, Thailand, Australia, Nigeria, China, and other nations. Coal is removed from mines that have been tunneled out under the sea. And many high-value, low-volume minerals including platinum, gold, silver, titanium, zirconium, chromium, and rare-earth minerals are removed from shores. The extraction of almost all minerals produces considerable amounts of waste, much of it toxic.

The most valuable nonrenewable resource is petroleum. About a third of the global supply comes from the coastal realm. Exploration suggests that considerable amounts remain in offshore deposits, where risks of extraction are often great. Reserves in high-latitude seas are subject to sea ice, harsh storms in winter, and a propensity toward severe earthquakes, such as off Russia's eastern Sakhalin Island and in the Sea of Okhotsk where exploration has recently begun. In the tropics, hurricanes are a constant threat.

Most offshore oil exploration has, until recently, been in shallow, continental-shelf waters. Given the continuing demand for petroleum, drilling is occurring farther out to sea and under more hazardous conditions. Drilling is now able to penetrate as deep as 8500 m or more. The extraction of hydrocarbons has many costly consequences beyond simply affecting sea life: for example, economic risks, land subsidence, erosion, and saltwater intrusion into freshwater aquifers.

1.3.1.3 Carving up coastal substrates

Substrate disturbance includes mineral mining, wetland ditching for public-health concerns and conversion for development, bottom trawling for fisheries, and dredging canals and ports for shipping. All of these activities are accompanied by resuspension and deposition of sediment elsewhere. Also, dynamiting and cyanide poisoning of tropical reefs are common practices for extracting fish; thus, reefs and fisheries are destroyed and the natural protection that reefs provide to shores against erosion is removed.

Use of mobile fishing gear for dredging and trawling produces among the greatest of impacts on coastal-ocean ecosystems. The physical effects are comparable to forest clear-cutting, but are estimated to affect approximately 150 times more area globally (Table 1.5). The frequency of dredging is also much greater than forest clear-cutting: some productive fishing areas are completely dredged up to three or four times per year. Dredging and trawling increase turbidity, alter benthic habitat, crush, bury, and smother non-target, sessile species, and expose infauna to predation. Hydraulic dredging to extract shellfish is less extensive than trawling for fish, but can be even more damaging as it leaves a highly disturbed benthos and creates a sediment wake that trails as a plume for some distance before sediment settles to smother benthic plants and animals far downstream. Of possibly even greater significance is release and reburial of nutrients and toxic substances, and oxygen depletion.

1.3.2 Introductions and additives

Humans continually add innovative products to watersheds and to the ocean's chemical soup that can affect biogeochemistry and the biota. Introductions include synthetic chemicals, toxic metals, trash, radioactivity, pathogens, exotic species, and excessive heat, noise, and artificial light. These enter directly from pipelines or offshore dumping, and indirectly when storms drench the land to wash solids, nutrients, metals, pesticides, pathogens, and other contaminants from streets, pavements, lawns, and farmlands. Anthropogenic introductions may be added slowly and chronically or suddenly and in concentrated forms, but rarely in accord with natural rhythms. Long-lasting carcinogenic, toxic, or lethal chemicals and metals collect into a contaminant profile when they accumulate within sediments.

Introductions originate mostly from the land. Many countries use the seas as dumps for land-based wastes and many nations and cities continue to dispose of untreated sewage directly into coastal waters. Even in developed, industrial nations, municipal sewage and toxic industrial wastes have been widely discharged directly into rivers and estuaries. Introductions also originate at sea. Ships increasingly collide with sea life, and substances that affect sea life are added through accidental (oil spills), and deliberate and routine operations (ocean dumping, bilge cleaning, antifouling paints). Equipment used in diverse ocean operations (fishing, monitoring instruments, submarines, submersibles, cables, military hardware, munitions, etc.) is often lost or discarded at sea. Occasionally, these introductions provide habitat opportunities for sea life (wrecks, artificial reefs, and floating materials that attract a variety of species).

Finally, introductions enter from the sky. Storms, winds, and rain transfer dust, plastics, debris, trash, nutrients, and microbes globally. Wind transports aerosols containing pollutants and nutrients, which fall with precipitation. Incomplete combustion from fossil fuel industries and automobiles releases metals and toxic chemicals to the air. Industrial plants introduce nitrogen and sulfur compounds that affect atmospheric chemistry, as is implicated in "acid rain". Radioactive materials released into the atmosphere from nuclear

Table 1.5 Comparison of forest clearcutting and trawling impacts.

Impact on:	Forest clear-cutting	Bottom trawling/dredging by fishing gear
Substrate	Exposes soils to erosion; compresses soils	Overturns, moves, and buries boulders and cobbles; homogenizes sediments; eliminates existing microtopography; leaves long-lasting grooves
Roots and infauna	Saprotrophs (that decay roots) are stimulated then eliminated	Infauna crushed and buried; others become susceptible to scavenging
Biogenic structures	Removes above-ground logs; buries structure-forming species	Removes, damages, or displaces structure-forming species
Associated species	Eliminates most late-succession species; encourages pioneer species	Eliminates most late-succession species; encourages pioneer species
Biogeochemistry	Releases large pulse of carbon to atmosphere by removing and oxidizing accumulated organic material; eliminates arboreal lichens that fix nitrogen	Releases large pulse of carbon to water column and atmosphere by removing and oxidizing accumulated organic material; increases oxygen demand
Recovery time to original structure	Decades to centuries	Years to centuries
Typical return time	40–200 years	40 days to 10 years
Global area affected per year	~ 0.1 million km^2 of net forest and woodland loss	~ 14.8 million km^2
Latitudinal range	Subpolar to tropical	Subpolar to tropical
Ownership	Private and public	Public
Scientific documentation (publications)	Many	Few
Public awareness	Substantial	Very little
Legal status	Modification of activity to lessen impacts and to prohibit or favor alternative logging methods and preservation	Activity restricted in only a few areas

From Watling & Norse (1998), with permission.

power plants and nuclear weapons testing, especially during the 1940s to 1960s, persist in some areas today.

1.3.2.1 Petroleum and related by-products

"Petroleum" is a broad term that describes naturally occurring and refined compounds and natural gases. Petroleum enters the coastal ocean from natural and anthropogenic sources, including submarine seeps, tanker accidents, deballasting operations, tank washing, refinery effluents, municipal and industrial discharges, losses from pipelines, offshore production, and industrial, municipal, urban, and river runoff. The United States National Research Council (NRC 2002) estimated that approximately 1.4 billion liters of petroleum and related hydrocarbons enter the oceans annually, chronically in low doses or catastrophically in high doses. A city of five million people might annually release roughly the equivalent of oil spilled when the tanker *Exxon Valdez* struck Bligh Reef in Prince William Sound, Alaska in 1989 and released approximately 37 000 tons of crude oil that spread more than 900 km from the spill site. This spill left an estimated 12% of its oil on subtidal sediments, affecting many species, some of which have apparently not yet recovered. The difference is that a city's input is chronic and an oil spill at sea is acute.

Oil spills can occur unpredictably at any time (Table 1.6). The effects are as varied as the contaminants themselves. Spills are most harmful in shallow, low-energy aquatic environments, sediments, wetlands, tidal flats, and sites with abundant wildlife. Relatively non-toxic petroleum tars that wash onto coastlines and beaches can smother biota and cripple recreation and tourism. Spills also result in oiling of birds, marine mammals, shorelines, and sediment, and release toxic substances that can affect marine life. The effects can be long-lasting or fleeting, depending on environmental conditions and the nature of the spill itself. The effects of spills are becoming fairly well known. However, little is known about how diffuse, chronic releases affect marine systems.