CHAPTER 2

History and Importance of Ocean Studies

CRITICAL CONCEPTS USED IN THIS CHAPTER

CC5 Transfer and Storage of Heat by Water
CC9 The Global Greenhouse Effect
CC10 Modeling
CC11 Chaos
CC16 Maximum Sustainable Yield
CC17 Species Diversity and Biodiversity

The dawn of ocean sciences. HMS Challenger is made fast to St. Paul's Rocks on the Mid-Atlantic Ridge—a hazardous task—during the first part of its 1872–1876 expedition.

The oceans have played a key role throughout human history. They have provided sustenance for humans for millennia. They have facilitated long-distance trade, served for transport of armies, and provided the arena for countless naval battles. They currently offer a source of recreation for hundreds of millions of people. However, the oceans' key role in mediating global climate and local weather is likely more important to humans than any of these other functions is.

Given the enormous importance of the oceans to human existence, one might expect our knowledge and understanding of them to be extensive and thorough. However, the oceans, which cover approximately 70% of the Earth's surface to an average depth of almost 4 km, are largely a vast domain that remains unvisited and unexplored. Amazingly, until the 1930s no human had ever descended below 150 m.

In this chapter we will review some of what has been learned about the oceans and about why they are so important to humans. Compared to other sciences, oceanography is young, and new, sometimes startling discoveries are made almost every month.

WHAT IS OCEANOGRAPHY?

Until recent decades, oceanography was primarily an observational discipline with greater similarity to geography than to other sciences. For many thousands of years, study of the oceans was limited almost entirely to exploring the surrounding lands and mapping the oceans and such shallow underwater obstructions to navigation as **reefs.** Such studies were important to facilitate trade and travel between known landmasses and islands. Considerable information was also gathered about the best places to find fish and **shellfish,** especially in the coastal oceans. However, for many centuries this biological information was documented only in the oral histories of local fishers.

Aside from limited studies by scholars of a few ancient civilizations, almost all systematic studies of the oceans have been carried out within the past 200 years. During these two centuries, mapping of the oceans has continued with ever-increasing sophistication (Appendix 4). Geological oceanographers have mapped seafloor topography and sediments. Physical oceanographers have mapped distributions of salt content, temperature, and currents. Chemical oceanographers have mapped distributions of chemicals in seawater and in seafloor sediment. Biological oceanographers have mapped distributions of algae, bacteria, and animal species. Mapping the oceans has been an enormous task that is far from complete, for reasons we examine later.

During the past several decades, oceanographers have moved beyond simply mapping the oceans to studying the processes that occur in them. As revealed in this text, the geological, physical, chemical, and biological processes in the oceans and overlying atmosphere are complicated and intimately interdependent. Consequently, oceanography (now often called “ocean sciences”) must be interdisciplinary.

To perform their work properly, oceanographers must understand all basic ocean processes, although they often specialize in one aspect. In oceanography, much information must be integrated to describe complicated processes. Therefore, the scientist must take a step beyond many of the traditional sciences that rely on reductive methodology, in which investigators reduce the complexity of a problem by studying only part of it (e.g., studying the effect of varying temperature on a single **species** rather than the combined effects of all environmental variables and competition from other species). Oceanographers must integrate and compare many observations of the ever-changing marine **environment,** often by using computer models (**CC10**), as well as performing reductive methodology experiments in controlled laboratory or field conditions.

EXPLORATION AND MAPPING

Through most of human history, the oceans have been studied primarily to facilitate seaborne travel and transport. Hence, early studies were directed primarily toward exploring and mapping the oceans.

Prehistory

We do not know when humans first began to use the oceans as a food source and for transportation—the two ocean uses that remain the most valuable to us today. However, humankind has used these resources for tens of thousands of years. The bones of marine fishes discarded by Stone Age people have been found in caves in South Africa that date back to between 100,000 and 70,000 years ago. In East Timor, near Indonesia, fish hooks that date back more than 38,000 years and bones of fishes that date back as far as 42,000 years ago have been found in a limestone cave. The fish bones came from species that live coastal waters and some species that live in the deep ocean far from shore: evidence that humans were using boats or rafts to fish in the open ocean. Also, humans are thought to have arrived on the island of Australia about 50,000 years ago. The first boats were probably built even earlier, perhaps for fishing on lakes or in the shallow coastal ocean, then later for transportation and colonization. The first boats or rafts may even have been made and used by *Homo erectus*, our immediate predecessor in the evolutionary tree. Recent evidence shows that *Homo erectus* lived on the island of Flores, Indonesia, at least 750,000 years ago. To reach Flores, *Homo erectus* must have crossed a wide, deep water strait that acted as a barrier to the migration of most other species.

Early human boats were made of wood, reeds, animal skins, or tree bark. These materials do not generally survive the centuries for archaeologists to study. The oldest boat found by archaeologists is thought to be a dugout canoe found in the Netherlands that was made between 10,200 and 9,600 years ago.

Ocean Exploration in Early Civilizations

Recorded history tells us that early development of ocean transportation and trade centered in the Mediterranean Sea, although the Polynesian and Micronesian cultures in the Pacific

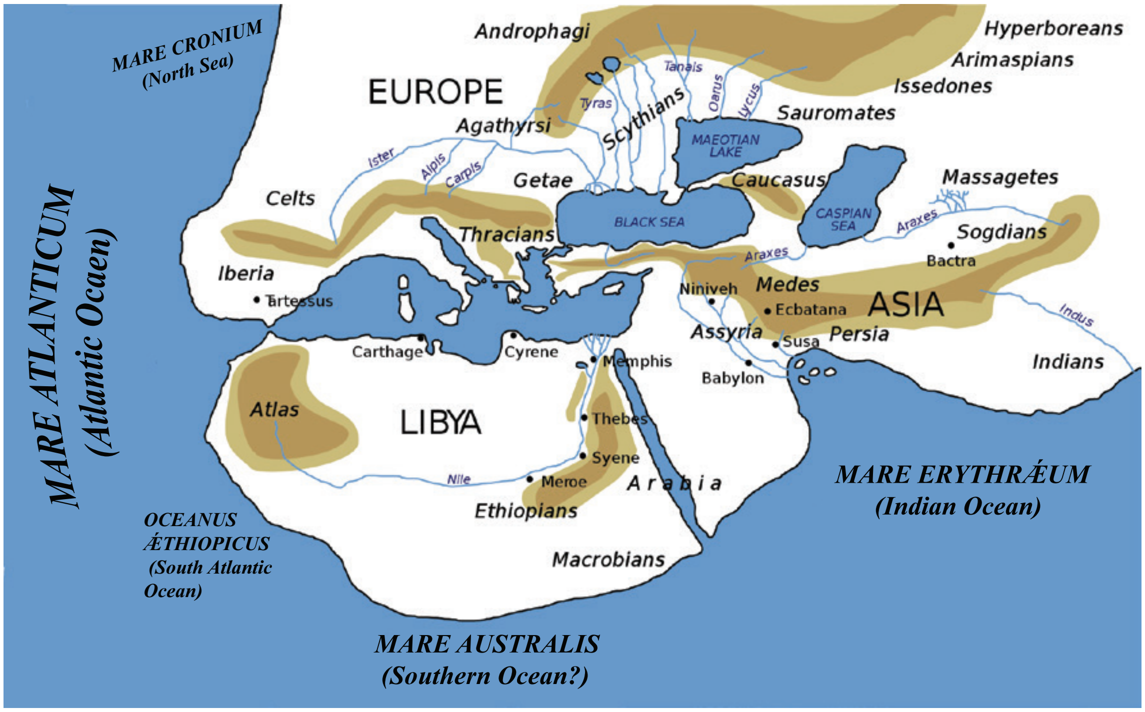


FIGURE 2-1 Map of the known world drawn by Herodotus in approximately 450 BCE. The oceans surrounding the known landmasses were thought to extend to the edge of the world. Compare this map carefully to a current Mercator projection, and you will see that the map drawn by Herodotus somewhat distorts longitude but quite accurately reproduces latitudes

FIGURE 2-2 A typical Polynesian outrigger canoe. This design has been used for centuries throughout much of Polynesia and Micronesia. This canoe was photographed in Papua New Guinea.

Ocean may have pursued these activities during the same period.

The Mediterranean.

The Minoan civilization, which prospered on the island of Crete in the Aegean Sea from about 3000 BCE, is considered the first recorded civilization to have used boats extensively for transport, trade, defense, and conquest. The Minoans' influence extended throughout the many islands of the Aegean, and legend records that a Minoan navy fought and controlled pirates in the region. Although seafaring capability continued to develop in the Mediterranean in both the ancient Greek and Egyptian civilizations, the Phoenicians, who inhabited areas that are now parts of Israel, Lebanon, and Syria, were the greatest of all the early Mediterranean seafarers. From about 1100 to 850 BCE, the Phoenicians were a great sea power, voyaging throughout the Mediterranean to Spain, Italy, North Africa, and even the British Isles, where they traded for tin. The Phoenicians also claimed to have made a 3-year voyage around the entire continent of Africa, but that claim has not been confirmed.

Much of the information needed to navigate from one port to another was a closely held secret of the navigator's art. However, maps that showed the shapes and sizes of coastlines and seas were made several thousand years ago. In about 450 BCE, the Greek historian Herodotus drew a map that is surprisingly recognizable as a generally accurate map of the Mediterranean and Red Sea region (**Fig. 2-1**). The most famous of ancient mapmakers was the Greek geographer Ptolemy, who lived around 150 CE. Ptolemy's maps, although little known until the end of the Dark Ages, about 1400 CE, were the basis of most maps until the 1500s.

Ptolemy's maps are remarkably detailed and accurate in their reproduction of north-to-south positions (**latitude**). However, they are distorted by substantial errors in east-to-west positions (**longitude**). For example, Ptolemy shows the east-to-west length of the Mediterranean to be about 50% too long in relation to its north-to-south dimension. These errors are a consequence of the mapmaker's inability to measure time accurately. Without precise and accurate time measurements, it was not possible to establish longitude correctly, as is discussed in Chapter 1. The east–west distortion of maps was not corrected until about the 1760s, when the first practical **chronometers** were developed that could keep accurate time on a ship.

In the 2000 years following the Phoenician era, ocean exploration slowed, and much of what may have been learned was lost in the turmoil of the Dark Ages. We know that philosophers did make several significant observations, especially during the early part of this period. In the sixth century BCE, Pythagoras declared the Earth to be spherical. In the fourth century BCE, Aristotle concluded that total rainfall over the Earth's surface must be equal to total evaporation, because the oceans did not fill up or dry out. In the same century, another Greek, Pytheas, sailed out of the Mediterranean to Britain, Norway, Germany, and Iceland. He developed a simple method of determining latitude by measuring the angle between the horizon and the North Star—a method still used today. Pytheas also proposed the concept that **tides** were caused by the moon.

In the third century BCE, Eratosthenes, a Greek studying at the library in Alexandria, Egypt, calculated the circumference of the Earth along a circle through the North and South Poles. His value of 40,000 km was very close to the 40,032 km that has been determined by extremely precise and sophisticated modern methods. Approximately 200 years later, Poseidonius incorrectly recalculated the circumference of the Earth to be about 29,000 km. Ptolemy accepted Poseidonius's incorrect value for his maps, and the error was not corrected for centuries. In fact, this error led Christopher Columbus to believe he had reached Asia when he arrived in the Americas in 1492.

Micronesia and Polynesia.

About 4500 years ago, at about the same time that ocean voyaging and trade were beginning to expand in the Mediterranean, the large islands of the far western Pacific and Micronesia were colonized. Expansion of humans into the islands of this area originated on mainland Asia and is thought to have proceeded through Taiwan. The expansion may have been made possible by the development of the outrigger canoe. After an apparent pause of about 1000 years, Polynesians colonized the islands of the western and central tropical Pacific reaching Hawaii and Easter Island about 900 AD. Unlike Mediterranean sailors, who could follow the coastline, the Polynesians had to navigate across broad expanses of open ocean to colonize the Pacific islands. The Polynesians crossed the ocean in double-hulled sailing canoes made of wood and reeds. A larger hull provided living space for up to 80 sailors plus plants and animals; a smaller hull or outrigger stabilized the vessel. The double-hulled design is still used in much of Polynesia (**Fig. 2-2**).

The Polynesians were arguably the greatest navigators in history. They successfully navigated across open oceans using only their memorized knowledge of the stars, winds, wave patterns, clouds, and seabirds. This knowledge was passed down through generations of the families of navigators, who were justifiably venerated in Polynesian culture. Both the Polynesians and Micronesians created some crude maps from wood sticks or rattan, but most Polynesian navigators did not use or need such maps. Some of the ancient Polynesian navigational knowledge persists today in the oral histories and experiences of just a few remaining descendants of the early navigators. Efforts have been made recently to sustain and preserve this knowledge through a series of ocean voyages across the Pacific in reconstructed replicas of ancient Polynesian boats, such as the *Hokule'a* (**Fig. 2-3**).

The recent journeys have proved that the ancient Polynesian navigation techniques were, and still are, remarkably accurate and reliable. There is great interest in discovering and documenting all the observational clues the navigators used. Much of the Polynesian navigational art is mysticized and undocumented, but the navigators must have known principles of wave shapes and directions, cloud formations, and other ocean phenomena that even now are not fully understood by modern scientists. For example, Polynesian navigators can deduce the location of an island hundreds of miles away by observing wave patterns created in the wake of the island. Modern science has been able to document such large-scale wave patterns around islands only since satellite observations of the sea surface became possible.

The Dark Ages and the New Era of Discovery

During the Dark Ages, when ignorance and anarchy engulfed Europe, ocean exploration by Europeans was limited. At that time, however, the Arabs were developing extensive seaborne trade with East Africa, India, and Southeast Asia. They were the first to use the **monsoons** to their advantage: voyaging from East Africa to Asia during the northern summer, when monsoon winds blow from the southwest, and returning in winter, when the winds reverse and blow from the northeast. The Vikings also made great ocean voyages during the Dark Ages, reaching Iceland in the ninth century and Greenland and Newfoundland late in the tenth century.

The middle and late 1400s brought the dawn of a new era as Europeans set out on many ambitious voyages of discovery. The Canary Islands off Northwest Africa were explored in 1416; and the Azores, in the middle of the Atlantic Ocean, were discovered in about 1430. The southern tip of Africa was rounded by Vasco da Gama in 1498; Columbus rediscovered the Americas in 1492; and the world was first circumnavigated by Ferdinand Magellan's expedition of 1519–1522, although Magellan himself was killed in the Philippines during the voyage.

Systematic mapping of the oceans began during the middle of the second millennium. After the mid-1400s, exploration of the oceans was incessant, and maps improved rapidly. However, most exploration was undertaken only to discover and colonize lands that could be reached by crossing the oceans. Systematic study of the oceans is generally not considered to have begun until 1768, when Captain James Cook began the first of three voyages to explore and map the Pacific Ocean (**Fig. 2-4**). Captain Cook was the first navigator to carry an accurate chronometer to sea. He therefore was able to measure longitude precisely for the first time and improve existing maps dramatically. On his voyages, Cook made many measurements of water depth, or **soundings**, which he accomplished with a lead weight attached to a rope. He measured depths to 200 fathoms (366 m). He also made many accurate measurements of water temperature, currents, and wind speed and direction, and he documented the occurrence and general characteristics of **coral reefs**. On his final voyage, Captain Cook died at the hands of Polynesian natives at Kealakekua Bay, Hawaii.

FIGURE 2-3 The Hokule'a. This vessel is a reproduction of the double-hulled voyaging canoes that the Polynesians used to explore and colonize the Pacific.

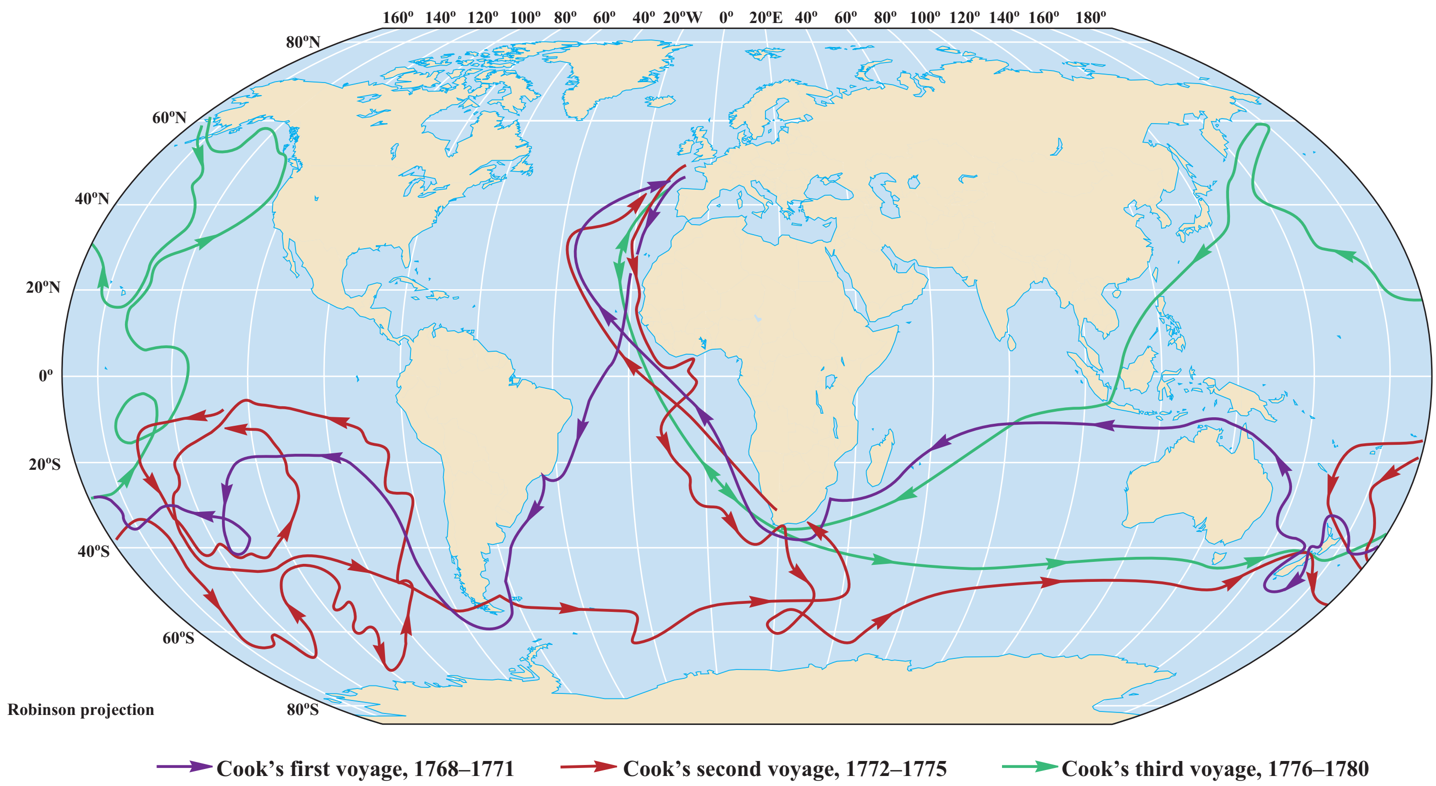


FIGURE 2-4 Routes of the three voyages of Captain Cook: 1768–1771, 1772–1775, and 1776–1780. Cook visited all the major oceans, traveling south into the waters near Antarctica and as far north as the Bering Sea. Places named after Captain Cook include Cook Inlet, Alaska; Cook Strait between the North and South Islands of New Zealand; and a group of Polynesian islands in the tropical Pacific near Tahiti.

At the same time that Cook was exploring the Pacific, Benjamin Franklin, then deputy postmaster for the American colonies, learned that mail ships that sailed the northerly route from Europe to the colonies took 2 weeks longer than ships that sailed the longer southerly route. Franklin's interest in that phenomenon led him to have many discussions with ships' navigators, from which he concluded that ships coming from the north were sailing against a great ocean current. From his observations, he and his cousin Timothy Folger were able in 1770 to develop a remarkably accurate map of the Gulf Stream current (**Fig. 2-5**).

The Birth of Oceanography

By 1800, several seafaring nations had established government offices with primary responsibility for producing charts that could be used by mariners to navigate safely and avoid reefs and **shoals**. Matthew Fontaine Maury, a U.S. Navy officer in charge of the Depot of Naval Charts, made a particularly significant contribution to the intensive ocean mapping efforts of the nineteenth century. Maury gathered data on wind and current patterns from numerous ships' logbooks, and he published his detailed findings in 1855 in a volume entitled *The Physical Geography of the Sea*. Maury also initiated cooperative efforts among seafaring nations to standardize the means by which meteorological and ocean current observations were made. Because of his many contributions, Maury has often been called the "Father of Oceanography."

The Beagle.

In 1831, a 5-year epic voyage of discovery was begun that forever changed the way humans view their world (**Fig. 2-6**). The major objective of the voyage of HMS *Beagle* was to complete a hydrographic survey of the Patagonia and Tierra del Fuego coastal regions to improve maps used by ships sailing between the Pacific and Atlantic Oceans around the tip of South America. The *Beagle* also visited the Galápagos Islands off the coast of Peru, crossed the Pacific to New Zealand and Australia, and returned to England across the Indian Ocean and around the southern tip of Africa.

The *Beagle* expedition has become famous primarily because of the young naturalist who traveled on the ship, observing the plant and animal life of the many places where the *Beagle* touched land. This naturalist was, of course, Charles Darwin.

FIGURE 2-5 Map of the Gulf Stream originally drawn by Benjamin Franklin and Timothy Folger in 1770

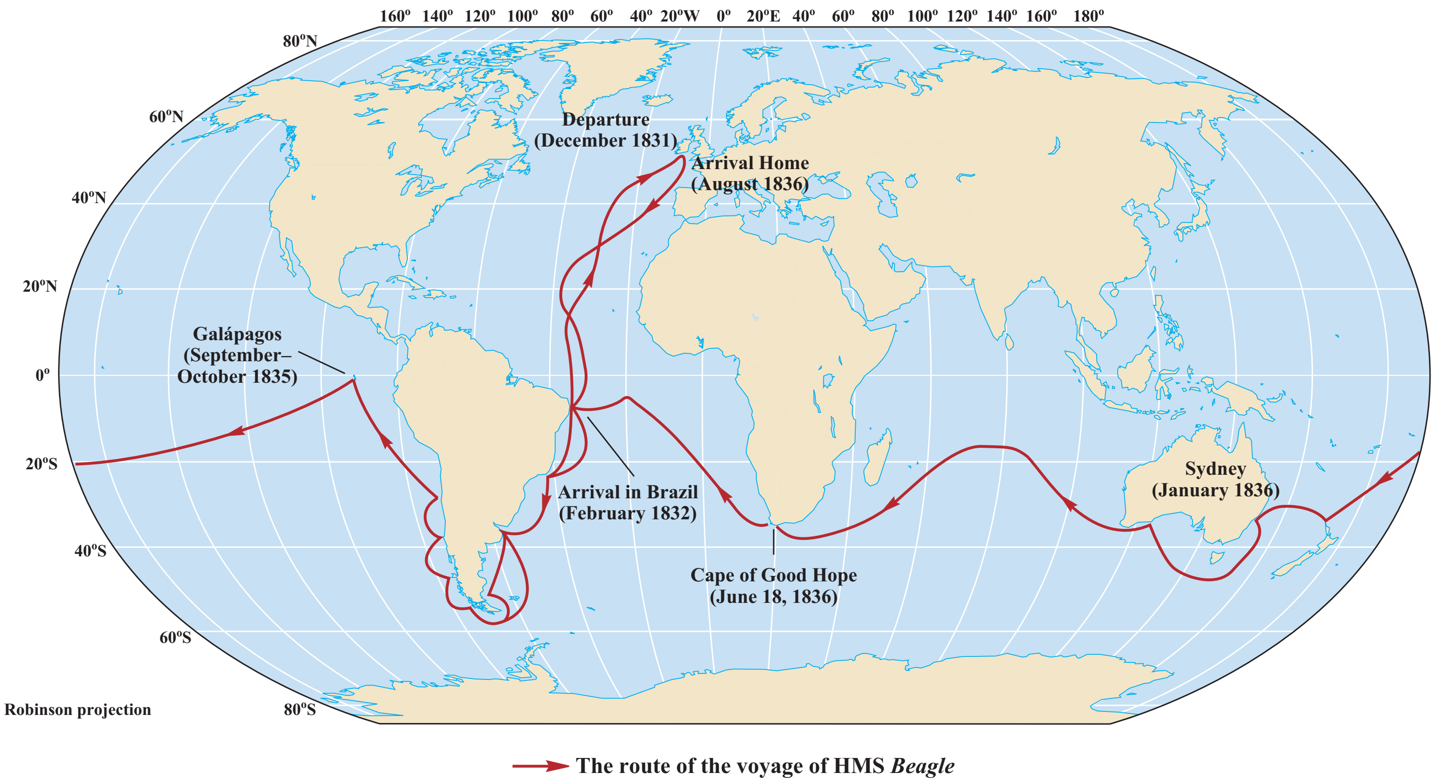


FIGURE 2-6 The voyage of HMS Beagle and Charles Darwin, 1831–1836. More than half of the voyage was spent in the vicinity of South America.

Darwin's observations on the *Beagle* expedition were the basis for his book *Origin of Species*, in which he proposed the revolutionary theory of natural selection.

Although the observations that led to the theory of evolution were the most famous of his findings on the *Beagle* expedition, Darwin also made several other major discoveries. For example, he proposed a theory to explain the formation of coral **atolls** that is still accepted (Chap. 4). In addition, he made a startling observation on one of his land excursions during the voyage: Darwin climbed high into the Andes Mountains, which run along the west coast of South America. At the top of these mountains, he found **fossils** in the rocks that were undeniably the remains of marine creatures. Darwin concluded correctly that the rocks had originated beneath the sea. Thus, he deduced that continents were not permanent and unchanging, as was widely accepted at the time, but that they must move, at least vertically. That observation remained almost unnoticed among Darwin's works until the twentieth century, when the theories of **continental drift** and **plate tectonics** were developed (Chaps. 4, 5).

The Challenger.

During the 1860s, British vessels performing investigations preparatory to laying a transatlantic telegraph cable brought up living creatures in mud samples from the bottom of the deep sea. At the time, the prevailing scientific opinion was that the deep ocean was devoid of life, because of the high pressures and low temperatures. Thus, the discovery of life on the deep-ocean floor was perhaps as dramatic a finding as the discovery of life on Mars would be if it were to occur today. The discovery of life in the deep sea led to the true birth of oceanography as a modern science, an event that can be traced precisely to the years 1872 through 1876. It was during these years that HMS *Challenger* sailed the world's oceans as the first vessel outfitted specifically so that its crew could study the physics, chemistry, geology, and biology of the oceans (**Fig. 2-7**). The *Challenger* was a sail-powered navy corvette with an auxiliary steam engine. For its scientific expedition, sponsored by the Royal Society of London, the corvette's guns were removed and replaced with laboratories and scientific gear. Included was equipment for measuring the ocean depths, collecting rocks and sediment from the ocean floor, and collecting seawater and organisms from depths between the ocean surface and the seafloor. The scientific additions crowded the vessel and left only spartan living quarters for the crew and the six scientists.

The *Challenger* sailed 127,500 km across the oceans during its 5-year expedition to study the North and South Atlantic Ocean, the North and South Pacific Ocean, and the southern part of the Indian Ocean. The expedition made hundreds of depth soundings using a lead weight on a hemp line that was hauled in by hand over a steam capstan. With this crude equipment, a single deep sounding required an entire day. Despite the extreme difficulty and tedium of obtaining deep soundings, the *Challenger* expedition was able to measure a depth of 8,185 m in the Mariana Trench east of the Philippines.

The *Challenger* also conducted

- Hundreds of observations of ocean water temperature, both near the surface and at depth-
- More than 100 dredge samples of rocks and sediment from the seafloor
- One hundred and fifty open-water net trawls for fishes and other organisms
- Numerous samplings of seawater
- Many readings of ocean current velocity and meteorological conditions
- Countless visual observations of fishes, **marine mammals,** and birds

The expedition brought back a wealth of samples and new scientific information about the oceans, including the identification and classification of almost 5000 previously unknown species of marine organisms. The quantity of data and samples obtained was so great that a special government commission was established to analyze the information. Indeed, the 50 volumes of research reports generated by the expedition were not completed until decades after the ship returned to England. The volumes contained so much information that they provided the foundation on which almost all major disciplines of oceanography were later built.

The Modern Era

In the more than 100 years since the *Challenger* expedition, oceanographers have traveled the seas in research ships ever more frequently, and with observation and sampling equipment of ever-increasing sophistication. Ocean research is still performed from research vessels in much the same way that it was in 1872. However, during the twentieth century, oceanographic research expanded to include exploration and study using **scuba** and manned **submersibles**, as well as unmanned observation using robotic vehicles and instrument packages either free-floating or attached to cables moored to the seafloor. Many of these instruments now report their data by **acoustic** links to the surface, and by radio signals sent through satellites to land-based facilities. In addition, oceanographers now make many observations from aircraft and satellites using remote sensing techniques. The introduction in 1978 of satellites specifically designed to look at ocean processes was a particularly important milestone because it allowed almost simultaneous observations to be made across an entire ocean basin for the first time. Satellites are now among the most important observing platforms used by oceanographers (Chap. 3).

The detailed history of oceanography since the *Challenger* expedition is too voluminous to include in this text. However, some of the important events are summarized in Appendix 4, and subsequent chapters review many of the more important findings of ocean study and exploration in the modern era. Among the most important events or discoveries during this author's lifetime have been

- The 1959 publication by Heezen and Tharp of the first comprehensive map of the ocean floor topography (Chap. 3).
- The discovery in 1964 and 1965 of hot, high-**salinity brines** and unusual black ooze sediments at the bottom of the Red Sea. This was the first observation of **hydrothermal vents,** although that was not recognized at the time.
- The first visit to a hydrothermal vent by the submarine *Alvin* in 1977, where a previously unknown type of **ecosystem,** based on **chemosynthesis** and sustaining hundreds of previ-

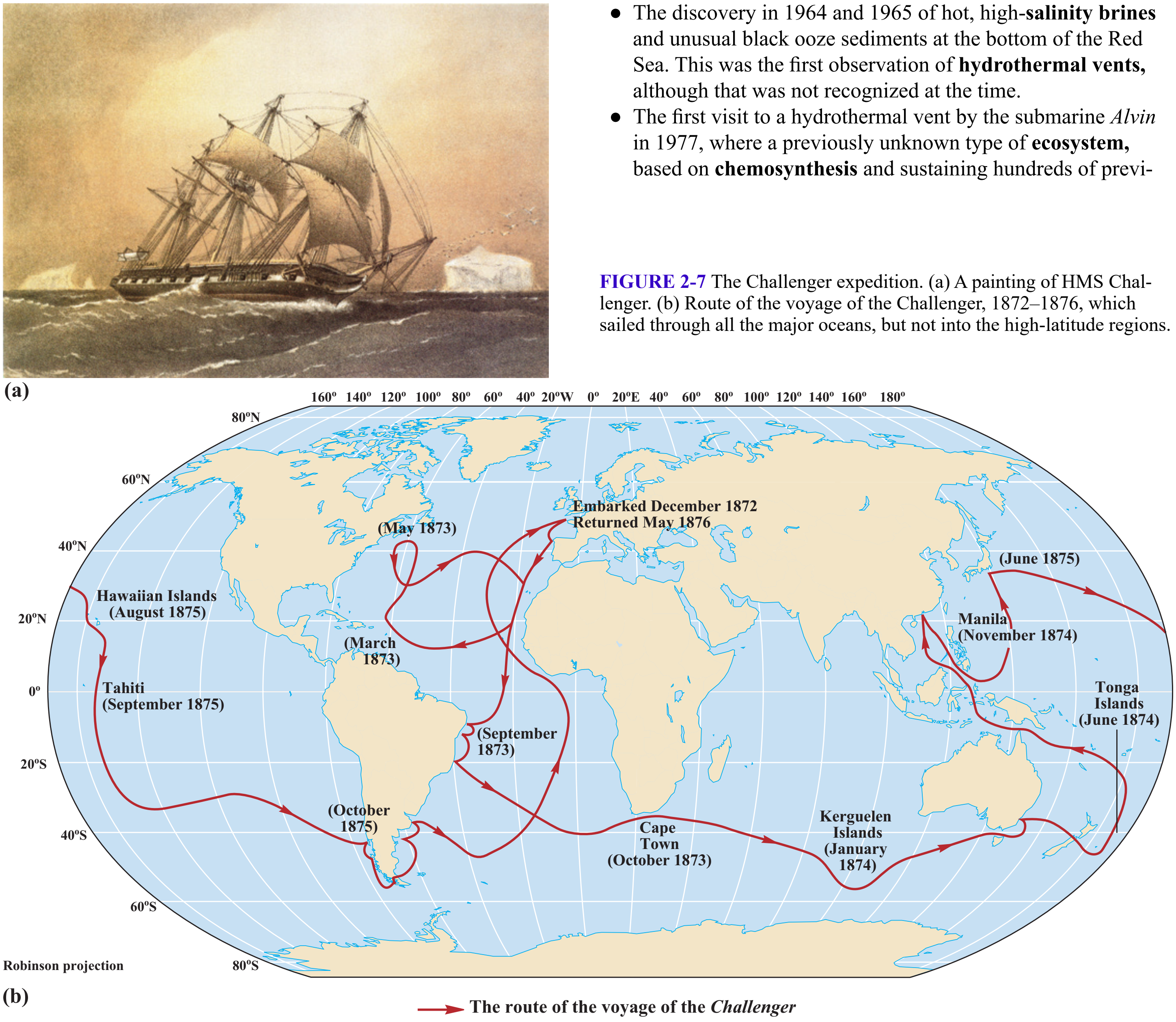


FIGURE 2-7 The Challenger expedition. (a) A painting of HMS Challenger. (b) Route of the voyage of the Challenger, 1872–1876, which sailed through all the major oceans, but not into the high-latitude regions.

ously unknown species was discovered.

- The steady accumulation of evidence that has led to the acceptance of Wegener's 1912 theory of continental drift (Chap. 5). Much of the crucial evidence supporting this theory was gathered by the Deep Sea Drilling Program, which for the first time obtained samples from deep within ocean sediments.
- The initiation of satellite observations of the world ocean that allowed, for the first time, a comprehensive snapshot view of the oceans. This view did not have to rely on many individual observations from ships and enabled the observation of large-scale dynamic processes as never before.
- The development of autonomous robotic measuring devices, including *Argo* floats, which allow the gathering of data of unprecedented detail about processes that occur below the surface layer and that cannot be observed by satellite sensors.
- The discovery of the horizontal gene transfer mechanism in the mid-1950s.
- The findings at the end of the 20th century, based on DNA analysis, that ocean life is dominated by microbial organisms

Each of these can arguably be claimed to be as important a breakthrough or advancement for ocean sciences as, for example, Darwin's observations on the voyage of the *Beagle* were to biology. We live in an exciting age of discovery for ocean sciences and many more surprises, advancements, and revelations are to come.

NATIONAL AND INTERNATIONAL LAW APPLIED TO THE OCEANS

Before we look at the various categories of ocean resources, it is important to realize that the oceans and their resources are not owned by individuals or corporations, as is much of the land area of the Earth, together with its resources. Instead, ocean areas adjacent to coasts are owned by governments, and ocean areas remote from land are not owned at all. To understand why this is true and what it means, we must review a little about the history of national and international laws as they relate to the sea.

Throughout most of history, the oceans have not been considered territory that could be claimed or owned. Indeed, until the 1600s, there was little thought or deliberation on the legal status of the oceans or the ownership of the associated resources. Individuals and nations were generally free to travel and fish anywhere in the oceans. In 1672, however, the British declared that they would exercise control over a **territorial sea** that extended 5.6 km (in British units, 1 league or 3 nautical miles) from the **coastline.** This distance corresponded roughly to the range of **shore**-based cannons. The 5.6-km territorial sea became commonly accepted as the standard for most nations and was formally accepted by the League of Nations in 1930. The remainder of the oceans outside the territorial seas, called the **high seas,** was considered to belong to no one, and in general, all nations were free to use and exploit high-seas resources.

The Truman Proclamation

The 5.6-km territorial sea remained almost universally accepted until after World War II, when President Harry Truman proclaimed in 1945 that "the exercise of jurisdiction over the natural resources of the subsoil and seabed of the continental shelf by the contiguous nation is reasonable and just" and that "the United States regards the natural resources of the subsoil and seabed of the continental shelf beneath the high seas, but contiguous to the coasts of the United States, subject to its jurisdiction and control." This proclamation, known as the Truman Proclamation on the Continental Shelf, was motivated by the "long-range worldwide need for new sources of petroleum and other minerals." The **continental shelf** was not defined in the proclamation. However, in a statement accompanying the proclamation, it was described as the land that is contiguous to the continent and covered by no more than 183 m (100 fathoms) of water. The 183-m depth was arbitrary because the continental shelf cannot be defined by a single depth (Chap. 4).

The Truman Proclamation caused a controversy and motivated a series of unilateral decisions by various coastal nations that claimed the resources under their own coastal oceans. However, there was no uniformity in the claims. Individual nations claimed jurisdiction over different widths of ocean off their coasts. For example, nations along the west coast of South America, where the continental shelf is very narrow (Chap. 4), claimed the resources offshore to 370 km (200 nautical miles). These nations went beyond the U.S. proclamation in another important way too: they extended their sovereignty over the entire 370-km zone, whereas the Truman Proclamation claimed jurisdiction only over the resources on or under the seafloor. Thus, these other nations were claiming ownership of the waters and fisheries in this zone, and the right to control any access to the zone by other nations' vessels.

"Law of the Sea" Conferences

In 1958 and again in 1960, the United Nations convened a conference on the "Law of the Sea." The conferences were intended to establish international uniformity in the ownership and access rights of nations to the resources of the oceans. The two conferences, attended by more than 80 nations, led to the adoption of several conventions. The conventions established a zone 22 km (12 nautical miles) wide within which nations had jurisdiction over fishery resources, and they affirmed that the "high seas" area beyond that zone was free for all nations to use for navigation, fishing, and overflight.

The conventions also attempted to define the right of coastal nations to own the seabed and sub-seabed minerals on the continental shelf. The continental shelf was defined as the area beyond the territorial sea out to a depth of 200 m or "beyond that limit, to where the depth of the superadjacent waters admits of the exploitation of natural resources." This definition was ambiguous. Coastal nations could claim the minerals out to a depth at which they could be exploited, and the size of this zone would expand as exploitation technologies improved. At the time, exploitation of seabed resources at depths greater than 200 m was considered unlikely. However, oil-drilling technology improved rapidly after 1960, and the United States was soon drilling in waters more than 200 m deep off California and more than 185 km (100 nautical miles) offshore in the Gulf of Mexico.

During the 1960s, the potential mineral resources of the deep oceans, particularly **manganese nodules** (Chap. 8), were first recognized. By the late 1960s, it was clear that more needed to be done to define and determine the rights of nations to use the oceans, particularly the rights to own and to exploit ocean mineral resources.

In 1967, the Maltese ambassador to the United Nations, Dr. Arvid Pardo, proposed that another Law of the Sea Conference be held. Pardo suggested a concept for a treaty that history may recognize as a critical turning point in the development of human civilization. His suggestion was that the ocean floor outside the zones of national jurisdiction should be reserved for peaceful uses, and that its resources should become the "common heritage of mankind." Pardo suggested that money generated from the exploitation of these resources be used for the benefit of less developed nations.

The common heritage principle subsequently has been applied to other global resources, including the atmosphere, Antarctica, and tropical rain forests. It is now an important basis for wide-ranging and growing international cooperation among nations. The common heritage principle was a major catalyst for the growing global understanding that the Earth's natural resources belong to all its peoples. The essence of the principle is that all nations have rights and responsibilities to protect the global environment and to use its resources wisely.

The Law of the Sea Treaty

In response to Pardo's call, the United Nations convened the Third United Nations Law of the Sea Conference in 1973. The conference met many times over the next 9 years. Finally, in 1982, the 151 participating nations adopted a new Convention on the Law of the Sea (commonly referred to as the "Law of the Sea Treaty") by a vote of 130 to 4, with 17 abstentions. The convention has now been signed by more than 150 nations. The United States was among the four nations that voted against adoption, even though many of the treaty provisions were originally written or supported by the U.S. delegation. The United States declared that it would not sign or ratify the treaty, because it did not agree with the ocean mining provisions, although it would follow many other individual provisions. Abstaining nations included the Soviet Union, Great Britain, and West Germany. As of February 2010, 161 nations have both signed and ratified the Treaty and a further 15 had signed the Treaty but not yet ratified it. The United States is the only major nation who has not ratified the Treaty. The United States signed the Treaty in 1994 but the U.S Senate has consistently refused to ratify it despite being urged to do so in 2007 by President Bush and subsequently by President Obama. However, the United States does recognize the Treaty as general international law.

Since 1982, the Law of the Sea Treaty has been the basis for numerous laws written by many nations about their individual rights to the oceans and ocean resources. Many provisions of the treaty are now widely accepted, and the treaty was ratified by the required number of 60 nations and became fully effective in November 1994. Also in 1994, the United States signed the treaty, but the treaty must still be ratified by the U.S. Senate. The principal provisions of the Law of the Sea Treaty can be summarized as follows.

A territorial sea of 12 nautical miles (22.25 km) was established, within which each individual coastal nation has full sovereign rights to all resources and to controlling access by foreign nationals. (Some nations, including Peru, Ecuador, Somalia, and the Philippines still claim territorial seas that extend to 200 nautical miles, despite the treaty.)

1. An **exclusive economic zone (EEZ)** was established outside the territorial sea. The EEZ normally extends out to 200 nautical miles (370 km), but exclusive rights to the sea bottom and resources below the bottom (but not the water column) can extend as far as 350 nautical miles (649 km) to the edge of the continental shelf where the shelf extends beyond 200 nautical miles. The edge of the continental shelf is defined by the treaty in geological terms, but in a way that is complicated and difficult to interpret in some areas. Within its EEZ, the coastal nation has jurisdiction over mineral resources, fishing, and pollution, and it may exercise control over access to the zone for scientific research.
2. Complicated procedures were established for drawing ocean boundaries of EEZs between nations that are closer to each

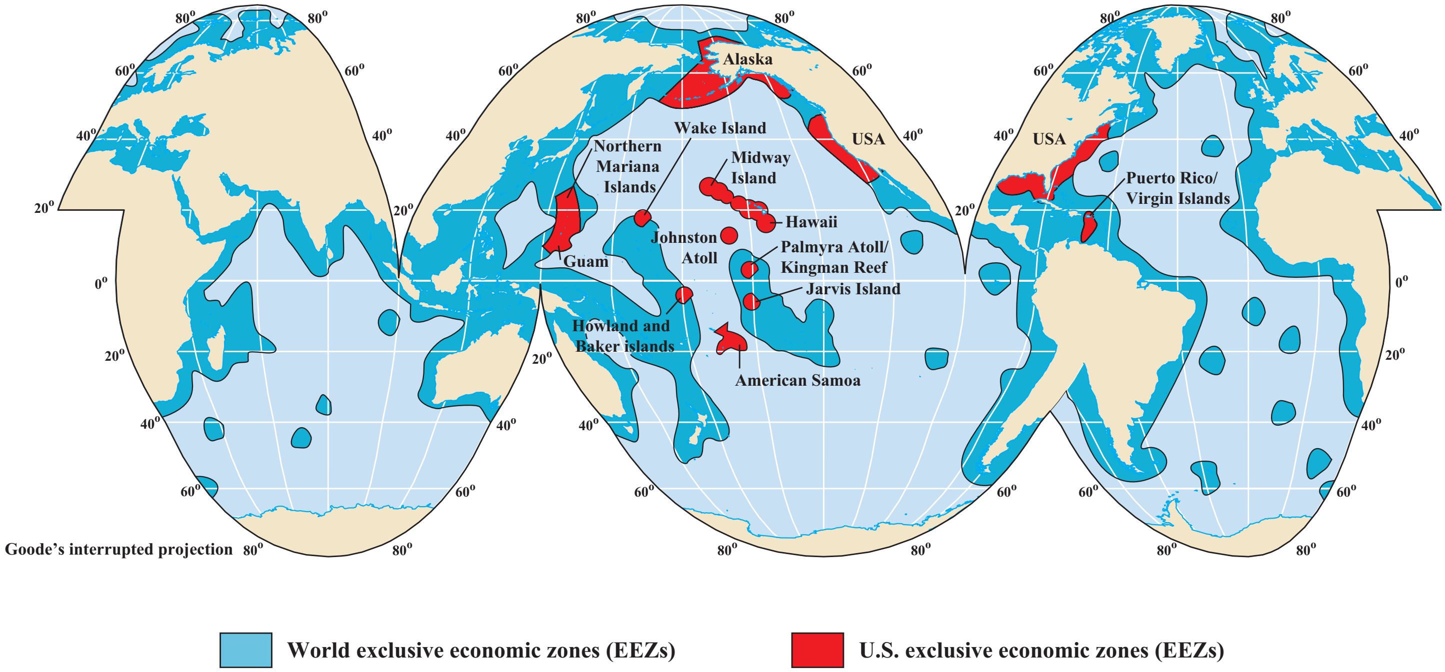


FIGURE 2-8 Exclusive economic zones (EEZs) of the United States and other countries. This map shows how large the U.S. EEZ is and how much of it is associated with Alaska, Hawaii, and various Pacific and Caribbean islands that are not among the current 50 states.

other than 400 nautical miles (740 km), or whose coastlines meet in complex ways.

3. The right of free and "innocent" passage was guaranteed for all vessels outside the territorial seas and through straits used for international navigation that are within a territorial sea (straits narrower than 24 nautical miles, or 44.5 km).
4. Complicated rules were established for exploiting mineral resources from high-seas areas outside the EEZs. All such exploitation would be regulated by a new International Seabed Authority (ISA). Any nation or private concern wanting to extract minerals from the high-seas areas would have to obtain a permit from the ISA to mine a given site. In return for the permit, the nation or private concern would provide its mining technology to the "Enterprise," a mining organization set up within the ISA. The Enterprise would mine a separate site that would be paired with the permit site. Revenue from the permit site would go to the permittee, whereas revenue from the Enterprise site would be divided among the developing nations.

The treaty did not include precisely defined procedures and rules for technology transfer to the Enterprise or for the disbursement of Enterprise profits among the developing nations. Those and all other decisions of the ISA would require unanimous approval of all nations party to the treaty. Unanimous consent of all the nations is virtually impossible to achieve, especially when resources and profits are at stake. Therefore, this provision was felt by many to destroy any reasonable chance that the ISA could succeed. Nations that voted no or abstained when the Law of the Sea Treaty was approved included most of the nations that were interested in deep-ocean mining of manganese nodules. No mining has yet been done under ISA auspices, but this may be primarily because deep-ocean mining is not yet economical. In 2001, the ISA did grant exclusive 15-year contracts to seven national and industrial pioneering investor groups for exploration (but not production) at sites in the eastern equatorial Pacific Ocean.

FIGURE 2-9 Boundary disputes in the South China Sea. Nations claiming ownership of one or more of the Spratly Islands include the Philippines, Vietnam, China, Taiwan, and Malaysia

Exclusive Economic Zones and extended Continental Shelf Rights

The Law of the Sea Treaty has exerted considerable influence over the actions of the world's nations. Most significantly, the EEZ concept is now almost universally accepted. If the 200-nautical-mile EEZ definition is applied uniformly, the total area placed under the control of the various nations is approximately $128 \bullet 10^{6}$ km^{2}, or about 35.8% of the world ocean (Fig. 2-8). The United States has a larger EEZ than any other nation, not because of the lengthy Atlantic, Pacific, and Gulf of Mexico coastlines of the contiguous states, but because of the vast additional EEZ area contributed by Alaska, Hawaii, Puerto Rico, the U.S. Virgin Islands, and the various U.S. Pacific protectorates and islands, including American Samoa and Guam (Fig. 2-8). Indeed, the U.S. EEZ encompasses an area of approximately $7.5 \bullet 10^{6}$ km^{2}, which is larger than the nation's land area. The U.S. EEZ contains many of the world's most productive fisheries and probably a large proportion of the mineral wealth of the oceans.

Unfortunately, the treaty definition of what can be claimed as a nation's continental shelf beyond the 200 nm EEZ is controversial and open to interpretation. The rules of how this definition should be applied were not adopted until 1999, and they are very complex. Nations are required to provide extensive data and evidence to define where the seafloor descending from the landmass just touches down on the relatively flat ocean bottom. This location is almost impossible to define or measure precisely. In addition, nations can claim undersea mountains and ridges if they are "continental appendages." Again it is virtually impossible to define and demonstrate this connection. Indeed, Russia has already applied the rule to claim the ridge that lies across the center of the Arctic Ocean floor, which almost all geologists would agree is an **oceanic ridge** and not an appendage of any continent. Many nations have already filed claims. However, resolution of these claims is likely to take many years.

The EEZ areas associated with islands are often very large. A single tiny **atoll** remote from any other island can command an EEZ of more than 0.2×10^{6} km^{2}, an area somewhat larger than the state of California. Ownership of such a large area is the real reason for many territorial disputes over the ownership of islands that formerly were considered inconsequential. The war between Great Britain and Argentina over the Falkland Islands in 1982 was motivated by the resources of the islands' EEZ. A dispute still continues between Japan and Russia over the Kuril Islands north of Japan. Probably the best example of an EEZ-motivated sovereignty dispute is the case of the South China Sea's Spratly Islands, which various nations claim to own. Although these tiny islands are inconsequential aside from the ocean resources that they command, various islands of the group are claimed by three or four nations (Fig. 2-9). Each of the claimant nations has stationed troops on one or more of the Spratly Islands, and tension often runs very high.

Sovereignty disputes over islands are not the only evidence of the importance of the EEZs. Many island nations, especially those in the Pacific, are extremely concerned about the possible reduction of their EEZs if sea level continues to rise, as predicted. In some locations, such as the Seychelle Islands in the Indian Ocean, a sea-level rise of only a few tens of centimeters would submerge low-lying islands, each of which commands an enormous area of EEZ. Even if sea level does not rise, the smallest islands may disappear through **erosion**. China claims sovereignty over a number of tiny islands in the South China Sea that are remote from any other island and the mainland. Many of these islands rise to only a few tens of centimeters above sea level, and they have essentially no economic value other than the up to 0.25 million km^2 of EEZ that each commands. Because wave erosion could soon eliminate some or all of these the islands, and to further its claim of sovereignty despite international court legal rulings against it, has committed large sums of money to dredge and fill and construct port and even airports the islands. While China's main motivation may be its sovereignty claim, it also hopes to protect and maintain the island. However, it is questionable whether such artificial means to preserve an island from sinking and so retain its EEZ are legal under the Law of the Sea treaty.

OCEAN RESOURCES

Most people know that the oceans are fished for seafood and used for transport and recreation, and that oil and gas are extracted from the seafloor. However, it is not widely recognized how valuable these resources are. For example, according to the U.S. Department of Commerce, U.S. ports handled more than $1.5 trillion in goods in 2016 and the recreational cruise industry contributed an estimated $37.8 billion to the U.S. economy in 2010. The same source reported that, in 2015, the seafood industry supported 1.2 million jobs and generated $144 billion in sales, while recreational fishing contributed 439,000 jobs and $63.4 billion. The Congressional Budget Office reports royalties from offshore oil and gas resources paid to the US Treasury averaged $8 billion per year over the period 2005-2014 and the National Ocean Economics Program reports the total value of offshore oil and gas produced in the United States in 2014 was $49 trillion. The National Economics Program also reports that in 2014, tourism and recreation based on the **coasts** and oceans supported more than 2.2 million jobs and generated $107 trillion in Gross domestic Product in the United States. There are also a number of other ocean resources or potential ocean resources that are not included in these figures. In the following sections, we briefly survey the wide range of ocean resources. For this purpose, we have chosen to group these resources in eight categories:

- Biological resources
- Transportation, trade, and military use
- Offshore oil and gas
- **Methane hydrates**
- Minerals and freshwater
- Recreation, aesthetics, and endangered **species**
- Energy
- Waste disposal

Biological Resources

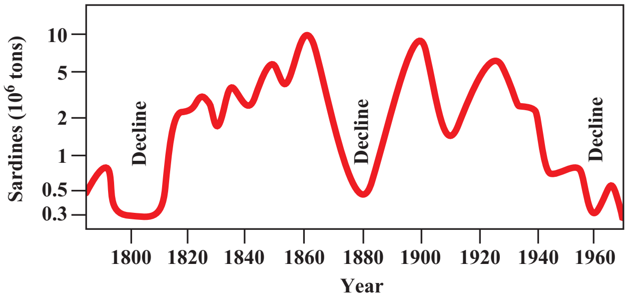
Fisheries:

Fish and shellfish are probably the most valuable ocean resources. Seafood has a very high protein content and is therefore of critical dietary importance. In many coastal areas, seafood is the basic subsistence food because no other significant source of food protein is available. Iceland and many Pacific Ocean island nations, including Japan, are good examples of such seafood-dependent areas. Fisheries are also a major part of the U.S. economy.

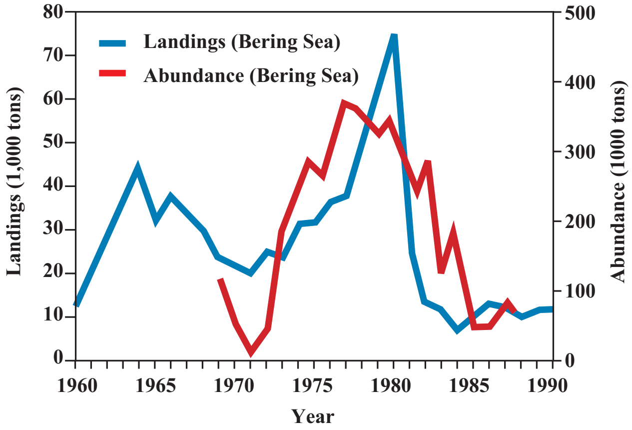
Until the past century, seafood resources were, for all practical purposes, inexhaustible because they were replaced by reproduction faster than they were consumed. However, human populations have burgeoned in the last 100 years and the demand for seafood has increased accordingly. Consequently, the seafood resources of many parts of the oceans have been exploited so intensively that many species are **overfished** and can no longer reproduce fast enough to replace their populations. Overfishing, which has resulted from a variety of technical and socioeconomic factors, poses perhaps the greatest threat to the health of ocean **ecosystems** other than climate change, ocean **acidification** and **deoxygenation.** Most scientists feel that overfishing is a far greater threat than the oil spills or industrial waste and domestic sewage discharges that often dominate media coverage of the oceans. Indeed, the increasing need for the greatest possible utilization of ocean fishery resources to feed a hungry and growing population, and the damage done to these resources by unwise exploitation and management, have been important factors in the development of oceanography.

Historically, fisheries were, and many still are, resources not owned by any person, organization, or government. The fact that they were free for anyone to exploit led to a vicious cycle repeated in fishery after fishery. When a new fishery opens, a few fishing boat operators are able to catch large quantities of the resource species with little effort and make substantial profits. Other operators, aware of these profits, quickly enter the fishery. As the number of boats increases and the population of the target species is reduced, each operator must expend more effort to catch the same amount of fish. At the same time, the value of the catch may decline because the market is now flooded with this species. In response, each operator increases fishing efforts to catch more and recover profits lost in the price drop. Hunting and catching technologies are continuously improved, and the fishing pressure continues to rise. If unchecked, the continuous increase in fishing effort and effectiveness quickly leads to a collapse of the fish population as the **maximum sustainable yield** is exceeded (**CC16**). Many fishers then look for a new species to target, and the cycle begins anew.

In such instances, the fishery resource has declined, sometimes so precipitously that the commercial fishery has been essentially wiped out for decades. The California sardine fishery that supported the development of Cannery Row in Monterey, California (**Fig. 2-10a**), the menhaden fisheries off the middle Atlantic coast of the United States, the cod fisheries off the coast of New England and Canada, and the king crab fisheries of the Bering Sea (**Fig. 2-10b**) are prime examples of such decimated resources, although environmental factors may also have contributed to the declines. Many other fisheries have also collapsed or may be close to doing so. Perhaps the greatest known historical decline was a decline of 10 million tonnes in the anchovy catch off Peru in just one year, 1970. This decline constituted roughly 10% of the total world fishery catch at the time. A strong El Niño was certainly responsible for some of the decline, but many scientists believe that excessive fishing efforts contributed greatly to the problem. Most major fisheries in the world are today being fished close to, or above, their maximum sustainable yield (**CC16**). When fishing is drastically reduced or halted



(a) California sardine



(b) King crab

FIGURE 2-10 The effects of overfishing. (a) A history of changes in sardine stocks off California, as deduced from fish scales in sediments. Note that the dramatic decline that occurred in the 1940s, when fishing was intense, is not unique. Hence, the stock may have declined because of natural factors, possibly compounded by overfishing. (b) King crab abundance in Alaska declined dramatically in the early 1980s, when fishing pressure increased substantially. Neither of these two fisheries has fully recovered.

for a species whose population has collapsed, the population for some species will recover. However, for other species, recovery never occurs because the species has been replaced in the food web by some other, often less commercially valuable, species. There is evidence that suggests that some fishes are steadily being replaced by jellyfish in many parts of the world ocean. This replacement may be caused by global climate change, but it is very likely that overfishing is also largely or partly responsible for any such changes.

The United Nations Food and Agriculture Organization (FAO) monitors fisheries statistics worldwide. FAO has reported that in 2013, 31.4% of fish stocks (usually all of a particular species) were being fished at unsustainable levels but they acknowledge that their data is less than perfect due to poor reporting of fishery statistics by a number of nations.

The rapidly growing recreational fishing industry also contributes to overfishing problems. For example, the recreational catch of striped bass on the east coast of the United States in 2004 was estimated to be about 2.4 million metric tons or more than twice the amount caught by commercial fishers.

Most traditional fisheries are in coastal waters near the consuming population. However, as coastal fisheries have been depleted, fishers have exploited resources from the deeper parts of the oceans and from distant coastal regions. The movement to far-flung ocean fisheries was accelerated by the development of refrigeration, which allowed catches to be stored and transported long distances in fresh or frozen condition. In addition, deep-ocean fisheries were traditionally free and open for anyone to exploit because no nation owned or controlled the resources. Unfortunately, the species that were the easiest targets of deep-ocean fishers were also those most vulnerable to overexploitation. The decimations of populations of many species of whales and seals are among the better-known examples of the overexploitation of ocean resources.

Overfishing is particularly serious in many developing countries surrounded by **coral reefs**. As modern medicine enables human populations in these countries to expand, the limited fishery resources of **reefs** near each village can no longer provide sufficient seafood for the growing population. Fishers are forced to exploit reefs in an ever larger area and must often resort to technological “improvements” in fishing techniques, such as dynamiting and spearfishing. Some of the fishes killed by dynamiting float to the surface for easy harvesting, but many of them sink and are lost to the fishers. Furthermore, dynamiting destroys the reef and **habitat** for the fishes that escape the blast or for future generations of fishes. Intensive spearfishing, particularly with **scuba,** can quickly remove breeding adults of a population and thus hinder reproductive replacement of the population. In these instances, technological advances in fishing have proven to be very destructive to the resources.

Fishing threatens not only the targeted species, but also other species in the food web**.** For example, harvesting and drastic reductions in sea lion and elephant seal populations in California during the Gold Rush era (mid to late 1800s) led to a sharp reduction in the population of their natural predator, the great white shark. The **marine mammal** population became protected by law in 1972 and has recovered substantially since the early 1980s, and the great white shark population has also slowly increased. The precipitous decline of the now rare Pribilof fur seal in the Bering Sea was almost certainly caused largely by increased fishing pressure on its principal food species, including pollack.

Fishing can also have adverse effects on marine species even if those species are not the target of the fishing and not dependent on the target species for food. Many fishing techniques are not efficient in selecting the target species. For example, turtles are often caught in shrimp nets, and considerable effort has now been made to develop nets that, although less efficient in catching shrimp, do not catch and kill the endangered turtles. Until fishing technologies were modified, many dolphins were caught and killed in nets set to capture large **schools** of tuna. Dolphins, sharks, turtles, and many nontarget fish species also are caught in kilometer long **drift nets** that form a barrier across the ocean **photic zone** and that capture, and usually result in the death of, anything large enough not to pass through the mesh. As in other fisheries, this incidental **bycatch** of “nonvaluable” species is simply discarded overboard. Such drift nets are now outlawed by most nations but, as with other illegal fishing methods, may continue to be used in areas far from surveillance by law enforcement officials. Enforcement of fishing regulations on the high seas is extremely difficult because no nation can afford to patrol the high seas adequately.

Bottom trawling, a widely used fishing technique where a net is dragged across the sea floor to catch bottom dwelling fishes has been identified as perhaps the most environmentally damaging fishing technique. These trawls destroy deep sea corals and other species in seafloor ecosystems. Many of the species in these seafloor ecosystems are extremely slow growing so trawling damage in some areas may not be repaired by re-colonization and re-growth for decades or centuries.

Many fisheries are now managed to avoid overfishing, but management is often ineffective because assessing the fishery stock size and its age composition is expensive and difficult. In addition, the maximum sustainable yield may vary dramatically from year to year because of the **chaotic** variations induced by natural factors (**CC16, CC11**). Consequently, managers have only a poor understanding of what maximum sustainable yield might be. Safe management requires that substantially less than the estimated maximum sustainable yield be caught each year to guard against errors inherent in the stock assessment data and against the inevitable years when stocks decline unexpectedly because of natural factors. However, managers are under pressure to allow the largest possible annual catch in order to provide adequate income to the owners and crews of fishing boats competing for the resource. Setting the catch “too low” would mean lost income and possibly jobs for fishers, as well as unnecessary “wasting” of some of the resource value.

A number of alternative management concepts are now applied to some fishery resources to address this problem. These include assigning catch quotas to individuals, individual boats, or communities and granting exclusive limited fishing access to defined geographic areas. Each of these regulatory approaches embodies the principle that access to the fishery resources is a privilege and that access to these resources should no longer be open to any and all persons who choose to fish. Another conservation approach— establishment of fishing-free natural reserves where fish populations can reproduce freely—is also now widely applied.

To this day, humans are primarily hunters and gatherers in the oceans, much as Stone Age people were on land. Human development from ocean hunter-gatherer to ocean farmer is long overdue. Mariculture (ocean farming) historically has been used on only a small scale in very few locations. However, it has developed and continues to grow rapidly, particularly in China, where it has been practiced for thousands of years, and in several other developing nations of the Pacific Ocean basin.

Other Biological Resources:

Apart from their aesthetic value, marine species are an important pool of genetic diversity. Many marine species have developed unique biochemical methods of defending themselves against predators, parasites, and diseases, and of detoxifying or destroying toxic chemicals. Therefore, marine species are a major potential resource for the development of pharmaceutical drugs and pollution control methods. The search for beneficial drugs and pollution-fighting organisms in the oceans is extremely tedious and has barely begun. However, a substantial number of potentially valuable pharmaceutical products have already been isolated from marine species and many are being tested for a variety of medical purposes. A number of pharmaceuticals derived from marine organisms have already become approved for human use. These include compounds isolated from marine sponges such as the antiviral acyclovir and the HIV/AIDS drug azidothymidine (AZT). Many of the compounds that show promise have come from rare ocean animals or algae found only in limited areas of certain coral reefs or other threatened ocean ecosystems.

Coral reefs are like the tropical rain forests of the oceans, in that they are the most promising sources of pharmaceuticals because of their extremely high species diversity. They sustain large numbers of candidate species, any one of which may contain numerous chemical compounds potentially valuable as drugs. Some such naturally occurring compounds have been used to design similar molecules that have similar drug properties but that can be industrially produced from widely available raw materials. Unfortunately, other pharmaceutically active compounds isolated from marine species may not be readily synthesized or redesigned. If this proves to be the case, conservation measures will need to be developed and enforced to prevent impoverished villagers who live near a reef from using destructive harvesting techniques to supply the pharmaceutical industry.

An example of what could happen is provided by the industry that provides fishes for tropical aquariums. A small but growing number of fishes bred in aquariums are beginning to enter the market. However, most tropical fishes sold in the aquarium trade in the United States are captured from Philippine reefs. Some collectors in the Philippines and elsewhere capture fishes by releasing cyanide into cracks in the reef, even though this practice is illegal. When cyanide is released into the reef, many fishes and other species die, but some fishes are not killed immediately. They swim out of hiding to avoid the cyanide, but they are stunned by the chemical and, therefore, are easily captured. As many as 90% of the fishes that survive the initial cyanide collection die of the cyanide’s effects during transport to the United States or after the buyer has placed the fish in a home aquarium. The ornamental (aquarium) fish market in the United States was estimated be worth about $3 billion in 2004. Only a very tiny fraction of this money ever reaches the collectors or is used to promote sustainable collection practices.

Transportation, Trade, and Military Use

Despite the rapid growth in air transport, surface vessels remain the principal and cheapest means of transporting cargo and people across the oceans. Large numbers of commercial, recreational, and military vessels enter or leave U.S. ports every day. The importance of the oceans for transportation is evidenced by the estimated $1.5 trillion in shipped goods handled by U.S. ports in 2016, and the $37.8 billion passenger cruise industry. In addition to this value for commercial ocean transportation, the oceans have important military uses. The oceans are plied by many surface naval vessels, but submarines have become particularly important, especially to the U.S. Navy, as platforms to transport and deploy ballistic missiles. As a result, during the past several decades intensive efforts have been made to improve ways to hide submarines and to find enemy submarines. Very extensive oceanographic studies, particularly studies of ocean surface and subsurface **currents** and of **acoustic** properties of the oceans, have been conducted to support these efforts.

The many benefits of our vessel use of the oceans for transportation, trade, military, and recreation do come at a cost to the ocean environment. Ships, particularly oil tankers, container ships, and naval vessels (especially aircraft carriers and submarines), have become progressively larger. The larger vessels require deeper ports and harbors and have increased the need for dredging of navigation channels in many bays, estuaries, and rivers. Dredging damages **benthos** at the dredging site. Dumping of the dredged material, which generally is done at a site in the estuary or coastal ocean not far from the dredging site, can also

FIGURE 2-11 Offshore oil and gas deposits occur throughout much of the U.S. Atlantic, Pacific, and Arctic Oceans, Gulf of Mexico, and Bering Sea continental shelves. The areas currently thought to hold the greatest potential reserves are the deeper continental shelf and continental slope of the Gulf of Mexico and the Arctic Ocean continental shelf.

have serious impacts (Chap. 16).

Offshore Oil and Gas

Oil and gas are extracted from beneath the seafloor in many parts of the world. Most of the undiscovered oil and gas reserves are believed to lie beneath the continental shelves and **continental slopes**. The search for the sedimentary structures most likely to yield oil or gas under the oceans, and the development of technologies to drill for and produce oil and gas safely and efficiently, have been intense throughout the past several decades. Oil and gas have been produced from wells drilled in shallow water for many years. However, technological developments have steadily extended capabilities for drilling in deeper and deeper waters, and in areas where **weather**, waves, currents, and sometimes ice conditions are progressively more demanding. The search for oil and gas, and the need to identify and control the environmental impacts of this search, are a consistent and important focus of recent oceanographic studies.

In the EEZ of the United States, the most extensive known oil and gas deposits are in the Gulf of Mexico. However, substantial known reserves are present beneath the continental shelves of the northeastern and southeastern United States, California, and Alaska (**Fig. 2-11**). There may also be many undiscovered deposits, particularly off Alaska. The offshore petroleum industry is among the largest natural resource development industries on the globe. Oil and gas are used primarily as fuel for vehicles, industry, and heating, but they are also the basic raw materials for plastics, pharmaceutical and other chemicals, cosmetics, and asphalt. Although **fossil fuel** burning may be reduced to prevent further buildup of atmospheric carbon dioxide (**CC9**), petrochemicals will still be needed in the future.

FIGURE 2-12 Structures of the offshore oil and gas industry. (a) These offshore exploration drilling rigs are under maintenance in Galveston, Texas. On the left, a typical jack-up drilling rig; on the right, a typical floating rig that rides on pontoons below the depth of most wave action. (b) Production oil rigs permanently emplaced in the seafloor of Cook Inlet, Alaska

Drilling is usually done from offshore platforms supported by long legs anchored to the seafloor (**Fig. 2-12a,b**). Floating platforms (**Fig. 2-12a**) also are used, especially in deep water, and drilling in the nearshore Arctic is done from artificial gravel islands. A production platform may tap into 100 or more wells that have been drilled into the seafloor below. Directional drilling, a process in which the well pipe is drilled downward and then turned underground to drill at an angle or even horizontally away from the drill site, now allows a single well to drain oil from an area as much as 12 km in radius and to recover more than 20 times as much oil per drill site or platform as was possible just a few years ago. On an ocean production platform, the well pipes generally extend up through the platform's legs. On the platform, oil, gas, and water are separated, and oil and/or gas are usually transported ashore through a pipeline laid on, or buried in, the seabed.

Methane Hydrates

Methane is released by the decomposition of organic matter. At low temperatures and high pressures, methane molecules can be trapped within the crystalline lattice of water ice crystals to form a combination called "methane hydrates" (on average, one molecule of methane for every five or six molecules of water ice). Methane hydrates were first observed in samples of cores drilled on land and the ocean floor several decades ago. These hydrates could be a potential source of methane, a clean-burning fossil fuel (it is completely combusted to carbon dioxide and water with virtually no chemical waste by-products or products of incomplete combustion such as are produced by the refining and burning of other fossil fuels). However, until recently, exploitation of this resource was considered unlikely for several reasons. Most importantly, methane hydrates are widely dispersed, usually occurring in the pore spaces of sediments and rocks.

Methane is rapidly released from the hydrates at normal atmospheric pressures and temperatures, but the deposits are generally too deep to mine and bring to the surface. However, several methods are now being tested that release methane from the hydrate in the sediment or rock so that it could be collected in a drill hole and recovered in the same way that petroleum and natural gas is recovered from oil and gas deposits.

In 2000, interest in methane hydrates was revived when some fishers dragged their trawl net at a depth of 800 m in a canyon about 50 km east of the mouth of Puget Sound in the northeastern Pacific Ocean. The fishers were startled to see their net rise to the surface filled with 1000 kg of icy chunks that were fizzing and melting. They hauled the "catch" aboard their vessel but quickly shoveled it back overboard because they had no idea what it could be. They tried to save samples in a freezer, but the low temperature alone was not enough to stop the methane from escaping the hydrate. The gas, expanding as it was released from the hydrate, even broke the containers in which they tried to store the hydrate. A year later, an ROV discovered what were described as "glaciers" of frozen methane hydrates forming outcrops on the seafloor about 50 km from where the fishers had found hydrates. Since that time, deposits of methane hydrates have been found on the seafloor or buried in shallow sediments in several other areas of the oceans, and they are now thought to occur in many parts of the world's oceans, especially on the continental slope.

The mechanism that forms methane hydrate deposits is poorly understood. Some hypotheses suggest that the methane is a product of the decomposition of organic matter buried in the sediments in **marginal seas** as the continents were pulled apart—the same source thought to be responsible for most of the world's oil and gas deposits (Chap. 4). Instead of being contained in nonporous rocks and converted to oil and natural gas, decomposing organic matter released methane that migrated through porous sediments and rocks until conditions were right for the formation of methane hydrates.

Methane hydrates are unstable except at high pressures and low temperatures, so they occur only below a depth of about 500 to 600 m in the oceans. However, these conditions are also present at relatively shallow depths beneath the frozen tundra of the Arctic regions. Not surprisingly, methane hydrate deposits have also been found in these environments. Estimates of the extent of methane hydrate deposits suggest that the total world resource may be more than 100 times the total volume of natural gas estimated to be recoverable from world oil and gas deposits. Thus, although most methane hydrate is widely dispersed and probably unrecoverable, if only 1% of the total were contained in concentrated deposits that could be recovered, the economic value would be huge. The methane would also be a very efficient and clean-burning fuel that could be readily adapted to most commercial and industrial energy uses. The first field test of the extraction of methane from methane hydrate deposits in the ocean was carried out in 2013 at a well drilled in the Nankai Trough, an ocean basin 80 km off the coast of Japan, Japanese researchers retrieved methane up to the surface over a period of one week from a water depth of 1000 m. Japan and China both successfully produced methane from test production wells in 2017, China drilling in the South China Sea, and Japan drilling off Japan's central coast. Japan plans full scale commercial production to begin between 2023 and 2027 while China plans to do the same by 2030. The United States has identified the presence of methane hydrate deposits in the Gulf of Mexico but, as of 2017 had no plans to perform test extraction.

Minerals and Freshwater

Ocean sediments contain vast quantities of mineral and material resources other than just oil and gas. They include sand and gravel (**Fig. 2-13b**), manganese nodules, **hydrothermal minerals, phosphorite nodules,** and heavy minerals such as gold that are often present in sediments of current or ancient river mouths (**Fig. 2-13a**). Sand and gravel are currently mined in large quantities from the shallow seafloor and used as construction materials in locations where no local land resources are available. At present, few efforts have been made to exploit other marine mineral resources. Cassiterite, a tin mineral, is dredged from shallow waters offshore from Thailand and Indonesia, and gold-bearing sands are dredged from shallow river mouth deposits offshore from Alaska, New Zealand, and the Philippines. Despite the limited scope of current ocean mining activities, there is substantial interest in future development. Mineral deposits thought to be most likely exploitable include phosphorite-rich sands as potential sources of phosphorus for fertilizer, manganese nodules, and seafloor massive sulfide (SMS) deposits laid down by hydrothermal vent activity as potential sources of metals including iron, zinc, copper, nickel, cobalt, manganese, molybdenum, silver, gold, and platinum.

Many mineral resources, particularly manganese nodules and hydrothermal minerals, are found primarily in the deep oceans far from land. The discovery of such mineral deposits has led to extensive oceanographic research to identify the processes that cre-

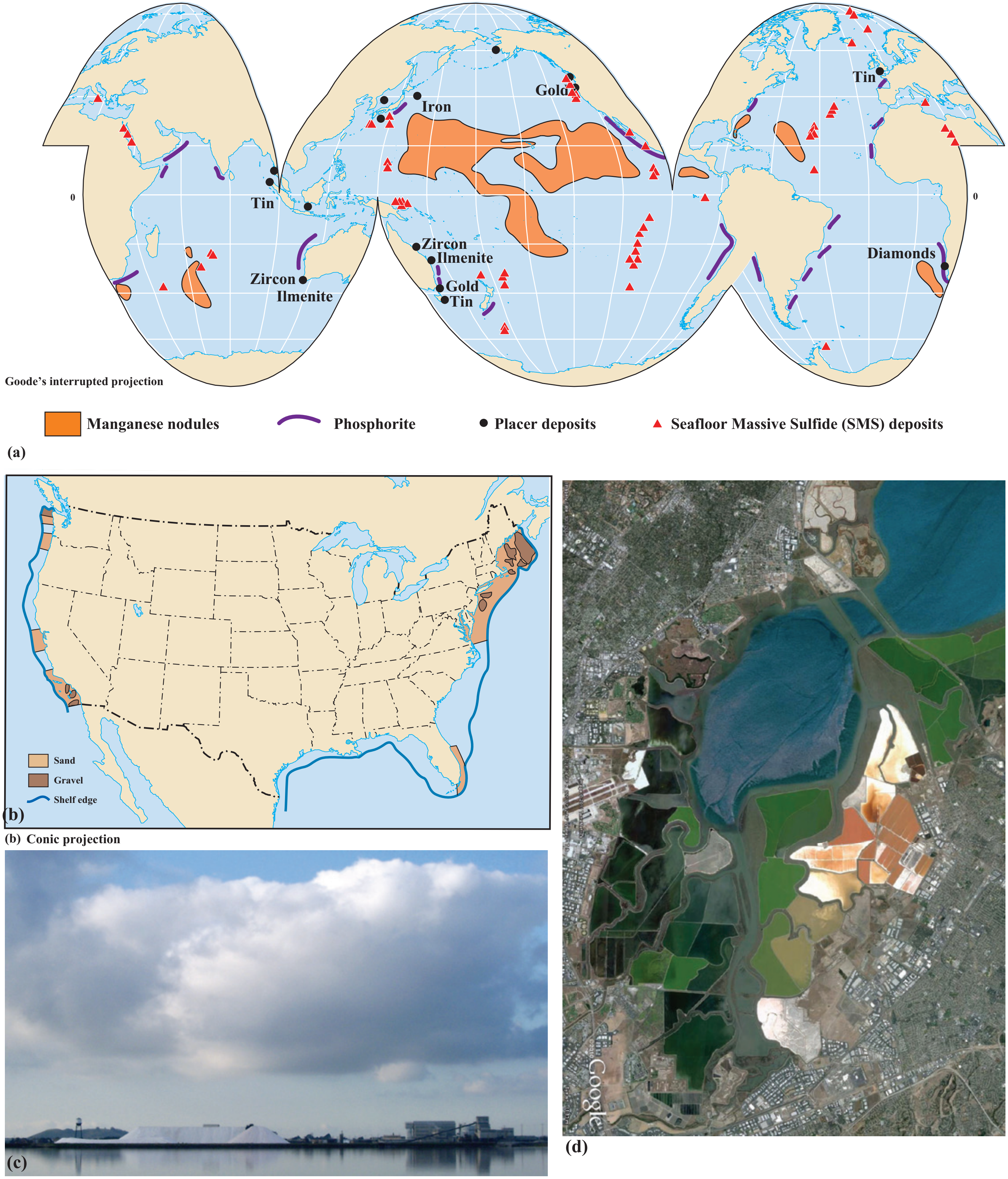


FIGURE 2-13 Some mineral resources of the oceans. (a) The principal mineral resources of the seafloor are manganese nodules that occur in areas of abyssal seafloor, phosphorite nodules and deposits that occur primarily on the continental shelf, and placer deposits (minerals containing gold and other heavy metals) that accumulate at river mouths. There are a number of commercial mining operations in different parts of the world, as well as other areas where potentially commercial deposits occur. (b) There are abundant sand and gravel resources on the continental shelves of the U.S. Atlantic and Pacific coasts in areas where fine-grained muddy sediments do not dominate. (c) Solar evaporation ponds are used to produce common salt in South San Francisco Bay, California. The large white mounds are piles of salt collected from the ponds and awaiting processing, packaging, and sale (d) This satellite image shows the evaporation ponds in South San Francisco Bay. The bright red and green colors are due to blooms of different algae species that grow at different salinities as water evaporates. The ponds are separated by levees.

ated them and to determine their distribution and abundance on the seafloor. At present, deep-ocean minerals are too expensive to mine in comparison to the dwindling, but still adequate, sources on land. However, the potential future value of those resources is considerable. If deep-ocean mining is developed, it may have significant environmental impacts especially if large quantities of fine-grained sediment are released into naturally clear waters of the open-ocean photic zone.

Until 1982, the mineral resources of the deep-ocean floor were not owned by any nation or individual and legally could be mined by anyone. During the 1960s and 1970s, a widespread fear arose in the international community that deep-ocean minerals might be exploited and depleted to the benefit of only one or two nations that commanded the technology to mine them. This fear was a principal driving force behind the negotiations that led to the Law of the Sea Treaty, described earlier in this chapter.

Table salt and freshwater are both produced from ocean waters. Salt is produced by evaporation in coastal **lagoons** (**Fig. 2-13c,d**). Freshwater is produced by evaporation or by reverse-**osmosis** extraction units. The process generates high-**salinity brine** wastes that are discharged to the oceans. The high salinity may have adverse effects on the **biota,** especially if water temperature is also high and causes additional stress. Such situations occur in locations, such as the Persian Gulf (especially off Saudi Arabia), where freshwater production from seawater is practiced most intensively.

Recreation, Aesthetics, and Endangered Species

Humans have probably always enjoyed living on the coast, not only for the ocean's food resources, but also for its aesthetic qualities and its moderating effects on climate (Chap. 9, **CC5**). It is the aesthetic qualities of oceans that have inspired poets and artists for millennia. However, only within the past generation or two have the oceans become popular for a variety of recreational activities, including sunbathing, swimming, surfing, sailing, luxury cruises, snorkeling, and scuba diving. With the development of such pastimes, a much wider spectrum of the human population now considers the ocean environment to be a special part of nature that should not be despoiled, as so much of the land has been. Underwater photography and video and the far-reaching impact of television have also introduced a large percentage of the human race to the beautiful, strange, and alien world of marine life.

As these recreational uses have become more popular, there has also been a growing recognition of the effects that such activities have on the marine environment. For example, anchor damage by boats carrying recreational scuba divers has become so severe in some locations that anchoring is now illegal, and boats must tie up to permanent mooring buoys installed at carefully selected locations on the most heavily dived reefs. Scuba divers also can damage coral reefs by breaking coral with their fins or hands. Although incidental contact with the reef and some coral damage is inevitable, most divers are now careful to protect the reefs on which they dive. Damage to reefs by divers is a significant problem only on the most popular reefs, where many divers are in the water every day. Where divers are only periodic visitors, the reefs are able to recover from any minor damage they may sustain. Indeed, damage occurs naturally as a result of the feeding and other activities of large reef animals, such as parrotfishes, and as a result of the effects of periodic strong storms. Sometimes such damage is even beneficial to the health and species diversity of coral reef communities (**CC17**).

Energy

As fossil fuels have been depleted, climate change concerns have grown and nuclear energy has lost favor, a major search has begun for alternate sources of energy. The oceans offer several potential sources of energy, including **tides**, waves, ocean currents, and thermal gradients. Full development of these energy resources, if it were possible, would allow substantial reduction in the use of fossil fuels and, consequently, in the release rate of carbon dioxide and air contaminants, such as sulfur dioxide, nitrogen oxides, and particulates. However, at present very little energy is generated from any ocean resource. Substantial engineering problems must be solved before ocean energy resources can contribute significantly to global energy demands. In addition, many questions must be answered about possible environmental impacts of ocean energy generation technologies.

The only ocean energy source currently exploited on a large commercial scale is the tides (Chap. 12). The technology used is exemplified by the tidal power plant at La Rance, France (**Fig. 10-21**). Because this technology requires a dam across the mouth of a bay or other inlet in which the **tidal range** is very large, relatively few locations are suitable (**Fig. 10-20**). To generate power during most of the tidal cycle and adjust to fluctuating energy demands during the day, water must be stored behind the dam during part of the tidal cycle and restricted from moving into the inlet during the **flood.** Consequently, tidal currents may be considerably reduced, **residence time** increased, and sedimentation altered in a way that can be detrimental to benthic biota, including valuable shellfish and bottom-dwelling fishes. The dam also hinders the passage of organisms and vessels.

A number of technologies have been proposed for energy recovery from currents. The most developed technology involves placement of huge fanlike turbines in a current, but many huge turbines placed side by side across the current are needed to generate significant power and existiing facilities are generally few and small, serving primarily isolated communites..

The nature and scope of possible adverse environmental effects of the proposed technologies are unknown. The major concern may be that modifying currents could have other far-reaching effects. For example, if enough turbines were deployed across the Gulf Stream to generate the power equivalent of several nuclear power plants, energy withdrawn from the current and the **eddy** motion caused by the turbines could conceivably alter the direction and speed of the Gulf Stream to some small extent. Even the remote possibility of such adverse consequences will probably prevent investment of the large sums of money needed to develop this technology.

The energy potentially available from ocean waves and currents is truly enormous, but such energy is widely dispersed and will not be easy to harness. Coastlines where wave energy is greatest, and therefore the potential for generating energy from waves is highest, are shown in **Figure 2-14a**.

Several design approaches have been developed to extract energy from waves, although none has yet been tested on a large power plant scale. One relatively simple design uses the rise and fall of water at the **shoreline** to compress air within a boxlike structure or shaft, which is open to the ocean only below the waterline (**Fig. 2-14b**). The compressed air drives a turbine. A variant of this design uses the upward and downward surge of water within an enclosed box or shaft to drive the turbine directly.

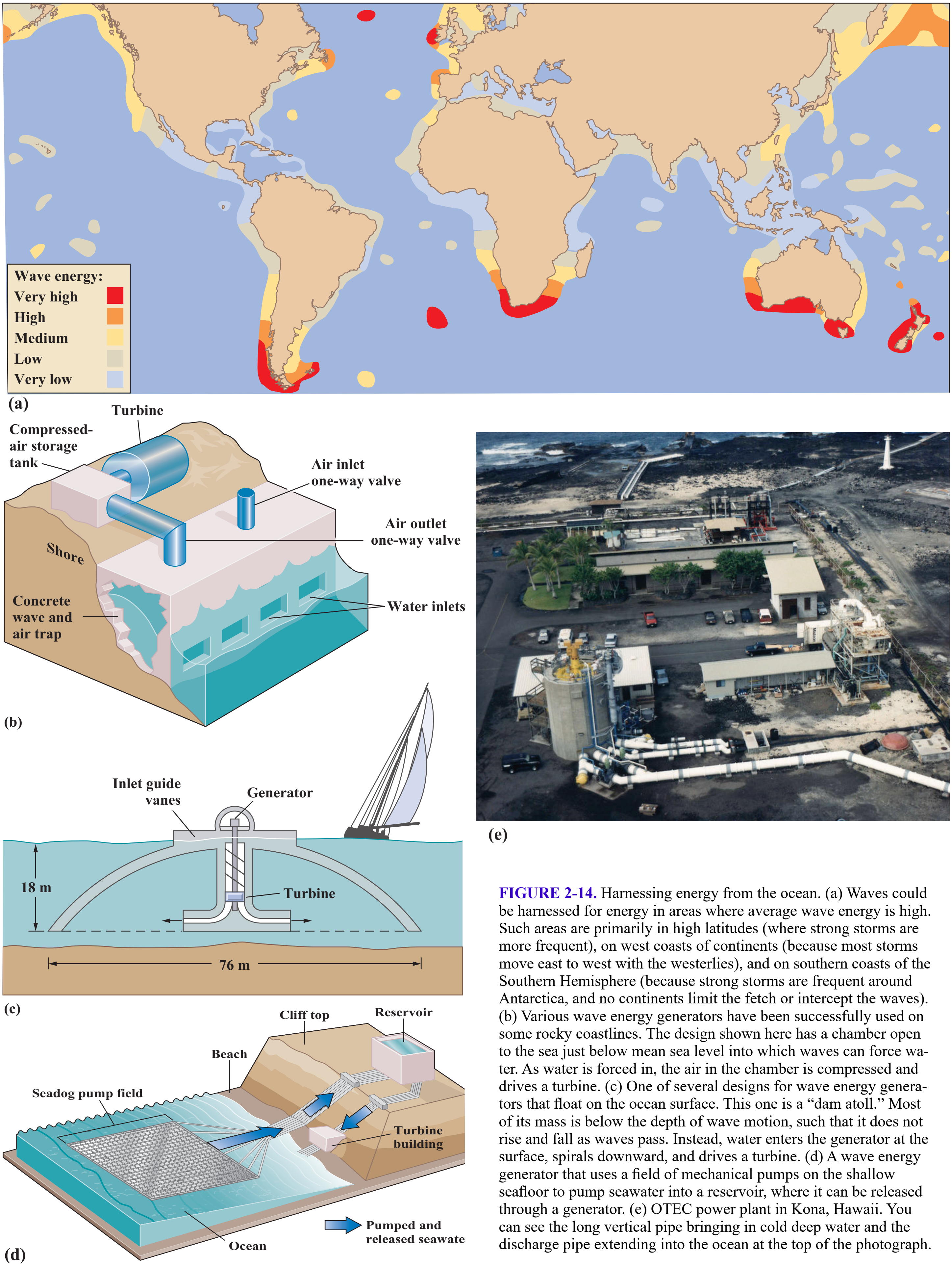


FIGURE 2-14. Harnessing energy from the ocean. (a) Waves could be harnessed for energy in areas where average wave energy is high. Such areas are primarily in high latitudes (where strong storms are more frequent), on west coasts of continents (because most storms move east to west with the westerlies), and on southern coasts of the Southern Hemisphere (because strong storms are frequent around Antarctica, and no continents limit the fetch or intercept the waves). (b) Various wave energy generators have been successfully used on some rocky coastlines. The design shown here has a chamber open to the sea just below mean sea level into which waves can force water. As water is forced in, the air in the chamber is compressed and drives a turbine. (c) One of several designs for wave energy generators that float on the ocean surface. This one is a "dam atoll." Most of its mass is below the depth of wave motion, such that it does not rise and fall as waves pass. Instead, water enters the generator at the surface, spirals downward, and drives a turbine. (d) A wave energy generator that uses a field of mechanical pumps on the shallow seafloor to pump seawater into a reservoir, where it can be released through a generator. (e) OTEC power plant in Kona, Hawaii. You can see the long vertical pipe bringing in cold deep water and the discharge pipe extending into the ocean at the top of the photograph.

Although these designs are simple and proven, they have limited value because they can be effective only on coasts with persistent strong wave action. In addition, multiple generators must be placed along a coast if large amounts of power are to be generated. Such structures would have adverse effects on the aesthetics of the shore and alter sediment transport along the coast. Generators of this type have been built to serve small coastal communities in Norway. Ironically, one of the first such installations was destroyed by severe storm waves soon after it was built.

Several wave power extraction devices have been designed to be deployed offshore. For example, the "dam atoll" is designed to focus waves toward a central generator shaft (**Fig. 2-14c**). A more recent design appears to overcome some of the disadvantages of earlier systems (**Fig. 2-14d**). In this design, a matrix of simple mechanical pumps would be placed just beyond the **surf zone,** where they would use wave energy to pump seawater up into a reservoir on the adjacent land. Power could then be produced, even when the wave energy was low, by release of the seawater from the reservoir through a turbine. The pumps would be submerged, minimizing the aesthetic impact. However, they would need to cover very large areas of seafloor and fill large reservoirs to produce as much power as a typical power plant, and the pumps would have to withstand wave impacts during even the largest storms.

Several wave energy generator designs have been tested with mixed success, but they would need to be deployed not far offshore in strings stretching along many kilometers of coast. They could be a navigation hazard and might interfere with movements of marine organisms, particularly marine mammals. Even worse, a string of such wave generators along a coast would drastically reduce wave energy at the shore. The result would be reduction of **longshore drift**, change of sediment **grain size**, and change of both the sedimentation regime and the associated biology of the nearshore zone. On rocky coasts, the important **supralittoral zone** with its unique biota (Chap. 17) would be particularly affected.

The quantity of ocean thermal energy that potentially can be exploited is huge and may be easier to extract than wave or current energy is. Ocean thermal energy conversion (OTEC) systems exploit the temperature difference between deep and shallow waters in the oceans to drive a turbine and generate electricity. The process by which energy is extracted to run the turbines is analogous to a refrigerator running backward, or a power plant operating at unusually low temperatures. Conventional power plants use heat from burning fossil fuel or a nuclear reaction to vaporize water in a closed container. The resulting high-pressure steam drives a turbine and is then condensed by cooling water to be recycled.

In OTEC, water is replaced by ammonia or another suitable liquid that is vaporized at much lower temperatures. The ammonia is heated by warm surface waters flowing over heat exchanger tubes through which it passes. Ammonia evaporates, and the resulting high-pressure gas drives a turbine. Once through the turbine, ammonia is condensed as it passes through another heat exchanger cooled by cold water pumped up from below the permanent **thermocline**. The ammonia is then recycled. An OTEC power plant is essentially built around a wide pipe that reaches to depths from which cold water can be pumped. Such systems have already been tested successfully.

OTEC is very promising and is probably the form of ocean energy generation most likely to contribute significantly to world energy needs. However, OTEC can be used efficiently only where surface waters are warm and cold deep waters are accessible—conditions found year-round primarily in tropical and subtropical **latitudes**. Locations where deep water is found close to land are ideal because long power transmission lines across the seabed would not be needed. In North America, only a few coastal locations, such as Hawaii (**Fig. 2-14e**), where an operating prototype and research OTEC facility has been operational since the 1980s, and the east coast of South Florida, are suitable. Pacific island nations are perfect locations, but the considerable investment needed to develop and build OTEC power plants is difficult for such nations to afford. Several operating OTEC plants are currently located in Japan, China and, on the French island of Reunion in the Indian Ocean, the largest being a 100 Megawatt (enough to supply about 50,000 homes) plant on Okinawa, Japan. Continued development the United States is uncertain but negotiations began in 2016 to design and build an OTEC plant on the island of St. Croix in the U.S Virgin Islands. OTEC may become a more attractive technology if proposed floating OTEC platforms are fully developed. Floating OTEC platform designs could use the electricity they generate to produce hydrogen by electrolysis of water. The hydrogen could be either transported ashore in tankers to be used as a fuel or used to generate ammonia (for use in fertilizer and chemical manufacturing) from atmospheric nitrogen.

Waste Disposal

The oceans have been used for waste disposal for thousands of years and, for most of that time, without significant harm to the marine environment (Chap. 16). Indeed, use of the oceans for sewage waste disposal has historically proven to be one of the most effective advancements ever made in human health protection.

Oceanographic research has documented a variety of problems caused by the disposal of certain wastes in parts of the oceans. Although the research has led to mitigation of many of the worst impacts, much remains to be learned. The oceans will undoubtedly continue to be used for waste disposal, and this may be the most environmentally sound management approach for some wastes. However, a much better understanding of the oceans is necessary to determine which wastes can be disposed of in this way, in what quantities, where, and how, without adversely affecting the environment or human health.

The oceans have a very great capacity to assimilate, safely and completely, large quantities of natural wastes if these materials are widely dispersed or released slowly enough that they are thoroughly mixed into the huge volume of the open oceans. Hence, the oceans suffered little from waste disposal practices until the past century, when human populations and modern industry began to grow explosively. Problems arose when cities and industries grew and became concentrated in large urban areas. This concentration caused the rate of disposal in many coastal and estuarine areas to exceed the rate at which the wastes could be dispersed and assimilated. Additional problems arose with the development of synthetic chemicals and materials, because the ocean ecosystem had no mechanisms to destroy or neutralize some of these substances.

Most of the wastes currently disposed in the oceans are liquids or slurries, and they are disposed of by being discharged through pipelines, called **outfalls,** into rivers, estuaries, or the coastal ocean. At one time, quantities of a variety of solid wastes, including chemicals, low-level **radioactive** wastes, construction debris, and trash, were transported to sea on vessels and dumped with the assumption that they would simply fall to the ocean floor, most of which was thought to be lifeless, and not cause any harm. Growing understanding of ocean ecosystems and the effects of ocean dumping have now led to the elimination of almost all dumping of solid wastes in the oceans. Dredged material is now the only waste material dumped at sea from vessels in large quantities.

Waste disposal and its effects in the oceans are discussed in detail in Chapter 16.

CHAPTER SUMMARY

What Is Oceanography?

Oceanography is an interdisciplinary science divided into subdisciplines of physical, chemical, geological, and biological oceanography.

Exploration and Mapping.

The oceans have been used for fishing for more than 100,000 years. Systematic ocean exploration began between about 6000 and 2000 years ago and was concentrated in the Mediterranean, Polynesia, and Micronesia. Subsequently, between about 2000 and 600 years ago, exploration apparently slowed for centuries, except in the Mediterranean.

After about 1400 CE, European and Mediterranean nations mounted many ocean expeditions. Scientific study of the oceans burgeoned. The voyages of Captain Cook (1768–1780), Charles Darwin and the *Beagle* (1831–1836), and HMS *Challenger* (1872–1876) produced some of the most important early systematic oceanographic studies.

Law of the Sea.

For most of recorded history, the resources of the oceans were not owned and could be exploited by anyone. In 1672, the British claimed ownership of a territorial sea that reached 5.6 km offshore. Such claims became common practice until 1945, when President Truman claimed for the United States ownership of the resources of the seafloor offshore to where the ocean reached a depth of 183 m. Many similar claims by other nations ensued. The resulting confusion was resolved by United Nations “Law of the Sea” conferences in 1958 and 1960, and passage in 1982 of a comprehensive Law of the Sea Treaty after more than a decade of negotiations.

The Law of the Sea Treaty grants to a coastal state ownership of all fisheries and mineral resources within an EEZ that is 200 nautical miles wide. The most controversial treaty provisions apply the principle that minerals of the deep-ocean floor outside of EEZs are the “common heritage of mankind.” The United States and several other nations did not sign the treaty because of these provisions. In 1994, enough nations ratified the treaty for it to become effective, and the United States signed it but has not yet ratified it..

The seabed and fishery resources of an EEZ can be very valuable. Consequently, sovereign nations now consider otherwise inconsequential islands valuable. The result has been a variety of territorial disputes, and even wars, over such islands.

Value of Ocean Resources.

The oceans provide abundant resources, including fisheries and other biological resources; transportation, trade, and military use; offshore oil and gas; methane hydrates; minerals and freshwater; recreation, aesthetics, and endangered species; energy; and waste disposal.

Biological Resources.

Most of the world’s major fisheries are overfished. The principal reason is that most fisheries are an unowned resource open to anyone who wants to exploit them. Many fishing techniques collect and kill nontarget species that are often discarded and bottom trawling severely damages slow growing seafloor ecosystems. Fishing line, nets, Styrofoam floats, and other items are discarded or lost and cause beach pollution. Aside from fisheries and the aesthetic value of marine species, ocean biological resources include ornamental species used in aquariums, and pharmaceuticals extracted or developed from marine species.

Transportation, Trade, and Military Use.

Most goods traded by humans are transported in surface vessels. The oceans are also extensively used by the world’s navies, both surface vessels and submarines. Research to support naval uses, especially hiding and hunting submarines, has been critical to the development of oceanography. Recreation on cruise liners and small craft is increasing rapidly. Occasional spills, especially from oil tankers, releases of oil from boat motors and ship engines, dumping of trash by some vessels on the high seas, construction of ports and portside facilities, discharge of bilge water, antifouling paints, anchors, and dredging to maintain navigation channels all have environmental effects, often deleterious.

Offshore Oil and Gas.

Most undiscovered oil is beneath the continental shelves and slopes. Offshore drilling and production platforms or islands are used throughout the world. These facilities have, on a few occasions, accidentally spilled large amounts of oil, and some of them discharge drilling muds and oily water.

Methane Hydrates.

Large accumulations of methane hydrates have recently been discovered in ocean sediments, especially on the continental slope. Because methane burns cleanly, methane hydrates could provide a large and desirable source of energy. Several nations are now testing technological means for extracting the methane economically. Environmental impacts are uncertain but could include accidental release of methane (a greenhouse gas) and disturbance of continental slope sediments that could cause turbidity currents and tsunamis.

Minerals and Freshwater.

Ocean mining for sand and minerals, although limited, is increasing. Mining alters habitat at the mine site and may lead to the discharge of tailings and other wastes. Coastal wetlands in some areas have been altered to construct evaporation ponds for salt production. Freshwater production from seawater generally discharges high-salinity brines.

Recreation, Aesthetics, and Endangered Species.

Human populations have historically been concentrated on the coast for its aesthetic values and moderation of climate. These values are becoming increasingly important as human use of the oceans for many forms of recreation increases. Humans and their recreational activities have many effects on the marine environment that are becoming better studied and understood. The protection of ocean ecosystems and species has emerged as an important goal, but difficult conflicts often occur between the need for protection and the need for resource uses.

Energy.

Winds, waves, tides, currents, and the temperature difference between surface and deep waters are all potential sources of energy. So far, only tidal energy is commercially developed. Facilities to generate energy from these sources may alter current, wave, and habitat characteristics and cause contamination from antifouling paints. OTEC may be the most promising technology, particularly for tropical island communities and is now in use in several locations outside the United States.

Waste Disposal.

The oceans are capable of assimilating large quantities of some wastes without any significant negative impacts. Wastes have been disposed of in the oceans for thousands of years, but increasing amounts have caused significant negative impacts on the ocean environment, especially when dumped or discharged in locations or by means that allow them to accumulate locally. Except for dredged material, most wastes now disposed of are liquids or slurries, such as treated sewage.

KEY TERMS

You should recognize and understand the meaning of all terms that are in boldface type in the text. All those terms are defined in the Glossary. The following are some less familiar key scientific terms that are used in this chapter and that are essential to know and be able to use in classroom discussions or exam answers.

acoustic
bycatch
chronometer
drift net
electromagnetic radiation
eutrophication
exclusive economic zone (EEZ)
foul
fouling
high seas
hydrographic
hydrothermal minerals
hydrothermal minerals
latitude
longitude
manganese nodules
maximum sustainable yield
nonindigenous species
outfall
overfished
phosphorite nodules
sounding
submersible
territorial sea
topography

STUDY QUESTIONS

1. Why did oceanography develop as an interdisciplinary science?
2. Why was the art of navigation developed to a much greater degree by the early Polynesian and Micronesian civilizations than by the contemporary European civilizations?
3. Why were early mapmakers able to measure distances accurately in a north–south direction but not in an east–west direction?
4. Why was the Challenger expedition so important to the development of oceanography?
5. Why don't we generate a significant amount of energy from tides, waves, and currents?
6. List the human uses and resources of the oceans.
7. Why is an international treaty that establishes a special set of laws for the oceans important?
8. Discuss how you would apply the "common heritage of mankind" principle to the protection and hunting of terrestrial wild animals whose habitats cross national boundaries.

CRITICAL THINKING QUESTIONS

1. During the early part of the Dark Ages, observations about the oceans were made by people we now call "philosophers." Today those who study the oceans are known as "scientists," not philosophers. Do you agree with this distinction? Why? What are some differences between philosophy and science?
2. In 1492, Columbus used Poseidonius's highly inaccurate calculation for the circumference of the Earth to identify the New World as Asia. Recall that Eratosthenes had calculated the circumference of the Earth with great accuracy well before Poseidonius. For what reasons do you think Columbus used the later, incorrect circumference?
3. Darwin's observations about evolution are well known. His ideas of continent movement (mountains once having been under the sea, for example) are just now being noticed. Why do you suppose this is?
4. For what reasons do you think the Law of the Sea Treaty established a limit of 200 miles for exclusive economic zones (EEZs)? Why do you think the treaty allows some nations to establish limits that are farther offshore than 200 miles? Explain why you think such exceptions should or should not be allowed.
5. Who has the right to decide who can use the biological and mineral resources of the oceans in areas outside the EEZs of the nations? Who should benefit economically from this use? How should use of these resources be managed, and by whom? If a nation disagrees with a management decision and allows its citizens to exploit these resources without following the internationally agreed-upon rules, how should the situation be resolved?
6. Who do you think should finance the search for beneficial drugs and pollution-fighting organisms in the oceans? Who should benefit economically from the discovery of such commercially valuable compounds? Who should benefit from harvesting organisms to make the compounds? How should the harvesting be regulated, and by whom?
7. Nearly 71% of the Earth's crust lies under its oceans. Available supplies of valuable minerals and oil and gas in the deposits beneath land are steadily becoming scarcer as they are depleted. Should minerals and oil and gas be removed from under the ocean? What factors need to be considered to make this decision?

CRITICAL CONCEPTS REMINDERS

CC5 Transfer and Storage of Heat by Water: Water's high heat capacity allows large amounts of heat to be stored in the oceans and released to the atmosphere without much change of ocean water temperature. Water's high latent heat of vaporization allows large amounts of heat to be transferred to the atmosphere in water vapor and then transported elsewhere. Water's high latent heat of fusion allows ice to act as a heat buffer reducing climate extremes in high latitude regions.

CC9 **The Global Greenhouse Effect:** Perhaps the greatest environmental challenge faced by humans is the prospect that major climate changes may be an inevitable result of our burning fossil fuels. The burning of fossil fuels releases carbon dioxide and other gases into the atmosphere where they accumulate and act like the glass of a greenhouse, retaining more of the sun's heat.

CC10 **Modeling**: Complex environmental systems including the oceans and atmosphere can best be studied by using conceptual and mathematical models. Many oceanographic and climate models are extremely complex and require the use of the fastest supercomputers

CC11 Chaos: The nonlinear nature of many environmental interactions, including some of those that control annual fluctuations in fish stocks, mean that fish stocks change in sometimes unpredictable ways.

CC16 Maximum Sustainable Yield: The maximum sustainable yield is the maximum biomass of a fish species that can be depleted annually by fishing but that can still be replaced by reproduction. This yield changes unpredictably from year to year in response to the climate and other factors. The populations of many fish species worldwide have declined drastically when they have been overfished (beyond their maximum sustainable yield) in one or more years when the yield was lower than the average annual yield on which most fisheries management are based. .

CC17 Species Diversity and Biodiversity: Biodiversity is an expression of the range of genetic diversity; species diversity; diversity in ecological niches and types of communities of organisms (ecosystem diversity); diversity of feeding, reproduction, and predator avoidance strategies (physiological diversity), within the ecosystem of the specified region. Species diversity is a more precisely defined term and is a measure of the species richness (number of species) and species evenness (extent to which the community has balanced populations with no dominant species). High diversity and biodiversity are generally associated with ecosystems that are resistant to change.

CREDITS

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