

# 6 Sustaining Our Oceans



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## Learning Outcomes

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After reading this chapter, you should be able to

- Describe the different types and the importance of ocean currents.
- Describe the different types of coastal and marine ecosystems and the role they play in providing ecosystem functions and services.
- Describe the different types of ocean pollution.
- Identify and analyze other major threats to our oceans.
- Describe different approaches to sustainable management of oceans.

We already know that all living organisms need nutrients to survive. In particular, the nutrients nitrogen and phosphorous are often a limiting factor in plant growth and productivity. For remote, forested regions of the Pacific Northwest of the United States, a major source of these nutrients is the Pacific Ocean, located hundreds of miles away. How does nitrogen and phosphorous from the ocean reach these forested ecosystems? And how have scientists been able to determine that these nutrients originated from the ocean in the first place?

The health of forests in the Pacific Northwest is in fact closely connected with the salmon that spawn and lay their eggs in the streams and rivers of those forests. Salmon are a type of *anadromous* fish, meaning that they are born in freshwater ecosystems; migrate to the ocean, where they spend most of their lives (typically 3 to 8 years); and then return to the same freshwater ecosystems to lay their eggs. These return migrations or “salmon runs” involve millions of fish swimming hundreds of miles upstream. Some salmon are caught and eaten by bears and other animals along the journey, while others reach their destination, lay their eggs, and die. The salmon carcasses are eaten by birds, bears, and other mammals and eventually even by salmon fry (baby salmon) when they emerge from their eggs. These salmon fry then make their way to the ocean to begin the cycle all over again.



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**Salmon swim upstream to their spawning grounds. Although the fish pictured are in Alaska, their journey is not unlike those in the Pacific Northwest.**

Because salmon gain 90% or more of their body weight while living in the ocean, they essentially bring nutrients from the ocean to their spawning grounds. Birds, bears, and other animals that eat these salmon carry those nutrients deeper into the forest and make them available to plants when they defecate or die. Scientists use a technique known as stable isotope analysis to determine the origins of nitrogen, phosphorous, carbon and other nutrients found in trees, bear bones, and other organic material found in the forests of the Pacific Northwest. In some cases as much as 60% of critical nutrients like nitrogen found in these forests are of a marine origin, suggesting that salmon are acting as huge “pumps” or “recyclers” of nutrients to forests in these regions (Cederholm, Kunze, Murota, & Sibatani, 1999). However, overharvesting of salmon and the construction of dams and other barriers that obstruct salmon runs have resulted in far fewer salmon reaching inland forests than ever before. As a result, some of these forests are being starved of nutrients as the numbers of salmon, a key-stone species in these ecosystems, decline.

The connection between salmon and inland forest ecosystems is just one example of the many links between life on land and life in the oceans. Oceans are a critical form of natural capital, and they provide numerous ecosystem functions and services that create or improve conditions for life on land. For example, ocean currents carry warm water and air from tropical regions to higher latitudes and create favorable climate conditions for human settlement.

Oceans also play a critical role in the carbon cycle and impact global climate. Evaporation from ocean waters contributes up to 40% of freshwater rainfall over land surfaces each year. And oceans are a major source of food for humans, a place of recreation and enjoyment, and a habitat for over half of all life found on Earth.

Despite their importance, we know relatively little about ocean ecosystems compared with life on land. Because the oceans are so vast and in some cases inaccessible, they represent something of a final frontier for exploration and scientific research on this planet. And because ocean ecosystems are mostly out of sight, we don't always understand or appreciate how our actions influence the health and productivity of this critical form of natural capital. This chapter will provide an overview of ocean currents and major ocean and marine ecosystems before shifting to major threats to the health of our oceans and the various approaches to protecting and sustaining them.

## 6.1 Ocean Currents

The world's oceans cover over 70% of the Earth's surface and contain over 97% of all water on the planet. All the major oceans are connected and essentially form one giant mass of water. However, scientists divide the world's oceans into five areas: the Atlantic, the Pacific, the Indian, the Arctic, and the Southern (or Antarctic) Oceans. The Pacific Ocean is the largest of these, covering almost one third of the Earth's surface and containing over half of all the water on the planet.

Because the oceans cover so much of the Earth's surface, they absorb a significant amount of incoming solar radiation. This radiation heats the oceans and helps drive a number of processes (like wind and waves) that result in ocean currents. Ocean currents, in turn, move vast amounts of water—and the heat that water contains—around the planet.

### Types of Currents

**Surface currents** move water horizontally along the surface of the ocean, while **vertical currents** move water between the surface and the deep depths of the oceans.

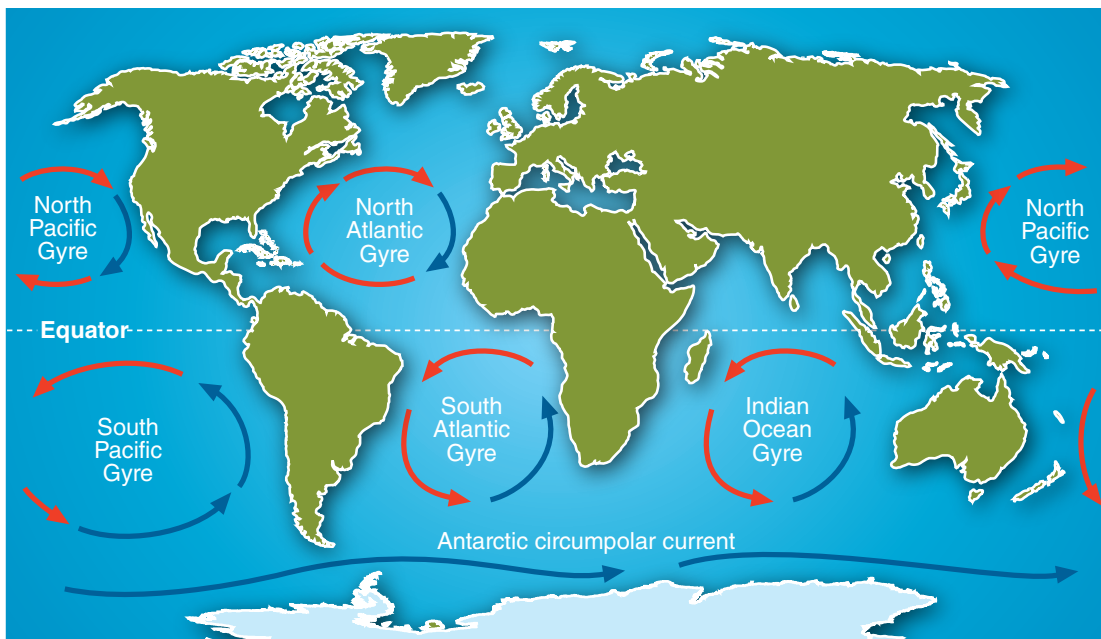
#### *Surface Currents*

Surface currents are driven by a combination of the Earth's rotation, winds, and differences in water temperature. In the tropical regions of the Atlantic Ocean, near the equator, the prevailing winds blow from east to west, pushing surface water west. Farther north, in the midlatitudes, the prevailing winds blow from west to east, pushing surface ocean water east. These two wind-driven movements of water in opposite directions set up what is known as a **gyre**, or a large-scale circular ocean current.

In the North Atlantic the gyre moves in a clockwise fashion as tropical currents move water from Africa toward Central America and the Caribbean, and midlatitude currents move water from the eastern coast of the United States toward Europe (see Figure 6.1). Further enhancing and contributing to this clockwise movement of ocean water in the North Atlantic is the **Coriolis effect**. As the Earth rotates from west to east, winds are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. This sets up clockwise gyres in the North Atlantic and North Pacific Oceans and sets up counterclockwise gyres in the South Atlantic, South Pacific, and Indian Oceans. The clockwise North Atlantic gyre is what drives the **Gulf Stream**, the major ocean current that brings warm water from the tropical regions around Florida and the Gulf of Mexico to the northeastern United States, northeastern Canada, and northern Europe.

### Figure 6.1: Major ocean gyres

Prevailing winds combined with the Earth's rotation (Coriolis effect) create large-scale circular ocean currents known as gyres. In the Northern Hemisphere ocean gyres move in a clockwise fashion. In the Southern Hemisphere they move in a counterclockwise fashion.



Source: Adapted from "What Is a Gyre?" by National Oceanic and Atmospheric Administration, 2018 (<https://oceanservice.noaa.gov/facts/gyre.html>).

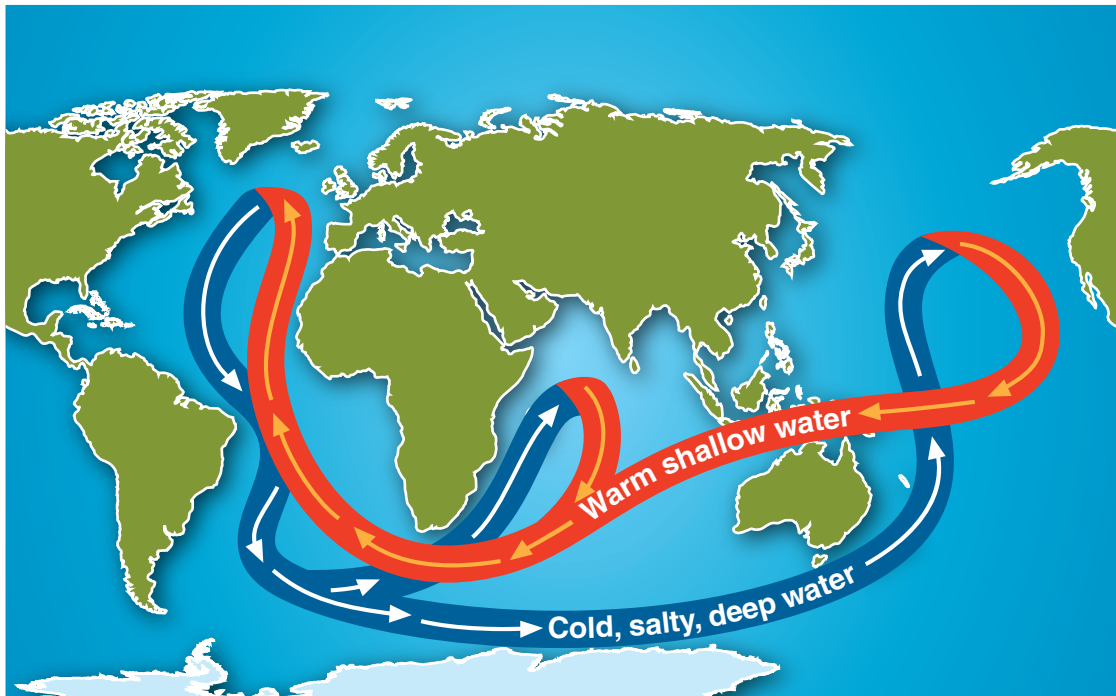
### Vertical Currents

Vertical currents are caused by differences in the temperature and salinity of ocean water. As ocean water becomes colder, it also becomes saltier, and saltier water is denser and heavier than less salty water. In the North Atlantic, as warm water moves from tropical regions near the Gulf of Mexico northward toward Canada and Europe, it becomes colder and denser. This increased density causes that water to sink and flow south again in a deep ocean current, allowing more warm water to flow into its place from behind before that water also cools and sinks. This vertical movement of water caused by differences in temperature and salinity is referred to as the **thermohaline circulation**.

The combination of surface currents and vertical currents results in a massive global circulation of ocean water known as “the ocean conveyor belt” or “the great ocean current” (see Figure 6.2). Whereas surface currents can move a molecule of water many miles in one day, the thermohaline circulation in deep ocean currents is a much slower process, sometimes taking hundreds of years to move a water molecule through a full global circuit.

### Figure 6.2: The ocean conveyor belt

The combination of surface currents and vertical currents results in a great ocean current that plays a key role in moderating weather conditions around the globe.



Source: Adapted from “Physics Division Annual Report,” by Argonne National Laboratory, 2001, p. 1 (<https://publications.anl.gov/anlpubs/2002/09/44218.pdf>).

## Learn More: Melting Ice and Disruption of Ocean Currents

In the North Atlantic, thermohaline circulation is what creates the Gulf Stream, and the Gulf Stream plays a critical role in carrying warmth and creating more moderate weather conditions in the northern regions of Europe.

However, climate scientists are now worried that the Gulf Stream conveyor belt could be slowing down and that this could plunge northern Europe into frigid conditions. The reason for this, ironically, is global warming. Global warming has resulted in a dramatic increase in the melting of Greenland's ice sheets. As more and more freshwater from these melting ice sheets enters the North Atlantic, it mixes with the salt water and makes it less salty and thus less dense. This could be slowing the rate at which this water sinks, thereby also slowing the rate at which warm water is pulled up from behind to replace it. The result could be a slowing of the Gulf Stream and a reduction in the amount of heat energy it carries to northern Europe.

This article from *Yale Environment 360* helps explain the research and scientific debate behind this phenomenon.

- [https://e360.yale.edu/features/will\\_climate\\_change\\_jam\\_the\\_global\\_ocean\\_conveyor\\_belt](https://e360.yale.edu/features/will_climate_change_jam_the_global_ocean_conveyor_belt)

## Impact on Weather

Another example of how ocean currents can affect our lives on land involves the **El Niño–Southern Oscillation (ENSO)**. Under normal conditions in the tropical Pacific Ocean, the prevailing winds blow from east to west. These winds push warm surface water from the western coast of South America toward Southeast Asia and the western Pacific region. This warm water builds up in the western Pacific and results in higher rates of evaporation and rainfall in places like the Philippines, Indonesia, and Vietnam. As surface water is pushed from east to west, it also allows colder water from the deep ocean to be pulled up to the surface along the western coast of South America—again, much like a conveyor belt. This **upwelling** of relatively nutrient-rich deep water results in ideal conditions for fisheries along the western coast of South America.

However, every 3 to 7 years this “normal” setup breaks down. ENSO refers to a situation in which those east-to-west winds weaken and warm surface waters collect in the central and eastern Pacific rather than the western Pacific. As a result, for 1 to 2 years, regions in the western Pacific that normally get a lot of rain instead experience drought, whereas typically dry regions along the western coast of North and South America experience heavy rains. Also, because the east-to-west surface current comes to a halt, the upwelling of nutrient-rich cold water along the coast of South America slows or ceases, and fishery productivity drops with it. Furthermore, altered cloud formations and atmospheric conditions in the tropical Pacific trigger a series of changes that shift weather patterns thousands of miles away. For example, in the United States, ENSO years typically result in heavier rainfall and snowfall along the

West Coast, warmer and drier conditions in the North, and cooler and wetter conditions in the South.

The movement of water through the Gulf Stream and the disruption of weather patterns caused by ENSO demonstrate just how closely linked life on land is with what's happening in the oceans. We'll see in Chapter 8 that there is growing concern among scientists that human-induced climate change could be impacting oceans in ways that could actually modify ocean currents. Such a shift in ocean currents could have profound effects on climate and weather conditions in highly populated and developed regions of the world and could lead to major disruptions in agriculture, transport, and other critical economic activities.

## 6.2 Coastal and Marine Ecosystems

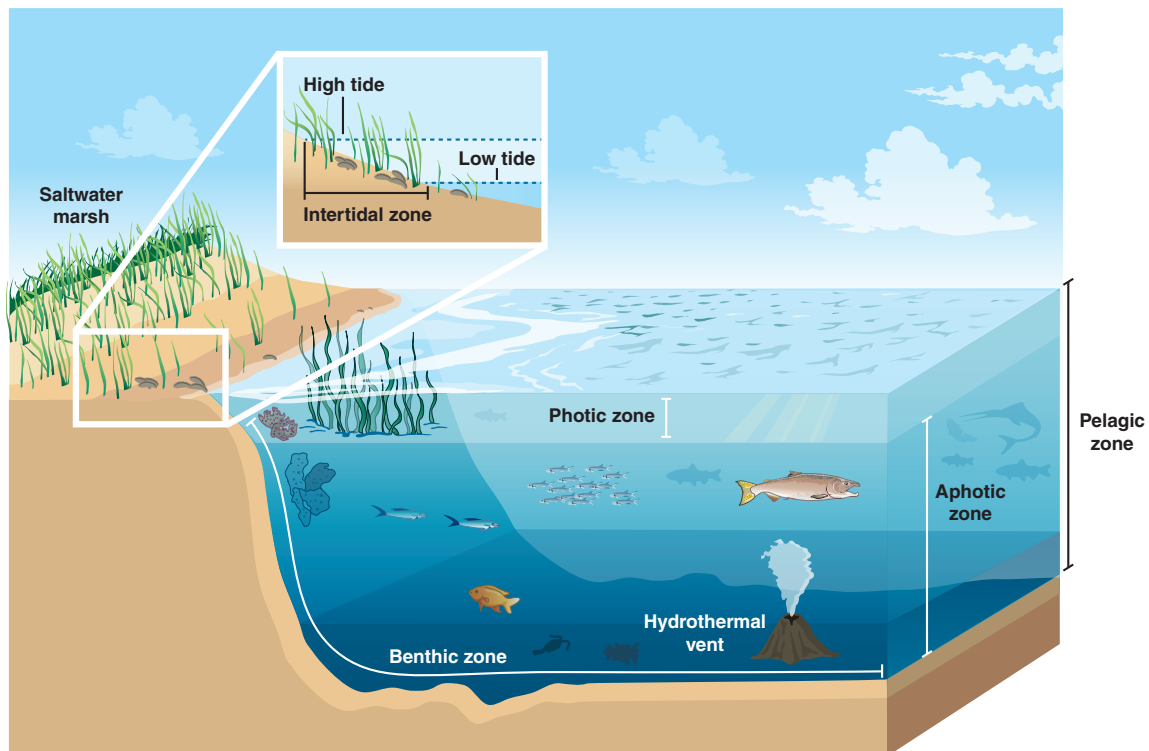
Long before there was any life on land, living organisms evolved and flourished in the world's oceans. Today the oceans are home to hundreds of thousands if not millions of species, with as many as 90% of them yet to be named and classified. The largest animal in the world, the blue whale, calls the ocean home, and these creatures can grow to 30 meters (100 feet) in length and weigh up to 181 metric tons. Yet it is the smallest of marine creatures, **phytoplankton**, that directly or indirectly sustains almost all life in the oceans. The surface waters of the world's oceans are teeming with billions and billions of phytoplankton, microscopic algae that can photosynthesize just like trees and other land-based plants. Phytoplankton form the base of the marine food web and are responsible for producing 50% to 85% of the oxygen on the planet. (Recall that one by-product of photosynthesis is oxygen.) Phytoplankton are eaten by larger microorganisms known as zooplankton, and zooplankton are eaten by even larger organisms, including fish and marine mammals. Just as land-based plants form the base of nearly all terrestrial food webs, these tiny "plants of the sea" are what support nearly all life in the oceans.

Waste products, including dead carcasses of plankton, fish, and other marine organisms, are constantly sinking toward the ocean floor. This slowly sinking shower of organic material is known as **marine snow**, and it plays an important role in maintaining life in marine ecosystems. Marine snow helps carry energy, captured by phytoplankton through photosynthesis, from light-rich surface waters to the increasingly dark depths below. Marine snow is an important food source for bottom-dwelling species of fish, crabs, and other organisms. And in much the same way that nutrients cycle on land, the nutrients contained in marine snow get cycled back to the surface through upwelling currents that carry cold water from the deep back to the surface. This is why fisheries off the western coast of South America tend to decline during ENSO events when upwelling currents slow down. Fewer nutrients being carried to the surface means fewer phytoplankton (remember, these ocean plants need nutrients just like other plants), and fewer phytoplankton means fewer fish.

Given the vastness and variety of conditions found across the world's oceans, scientists divide them into different zones and habitats. The most basic distinction is between three different zones: intertidal, benthic, and pelagic (see Figure 6.3).

## Figure 6.3: Oceanic zones

The ocean can be divided into three basic zones: intertidal, benthic, and pelagic. The pelagic zone can be further subdivided into the photic and aphotic zones, based on where light penetrates.



### Intertidal Zone

The **intertidal zone** occurs where oceans meet the land, specifically between the highest levels of high tide and the lowest levels of low tide. Abundant light, nutrients, and oxygen tend to make intertidal areas both highly productive and characterized by a high diversity of species, but constantly shifting conditions and wave action also make life here challenging. Organisms that live in intertidal zones—such as barnacles, mussels, oysters, seaweed, crabs, and sea stars—must be able to tolerate a constant cycle of being either underwater or exposed to the air, sun, and waves. Some organisms do this by anchoring themselves to rocks, while others constantly move about and burrow under sand and rocks for protection.

Examples of critical ecosystems that are found in the intertidal zone area include estuaries, salt marshes, and mangrove forests.

### *Estuaries and Salt Marshes*

**Estuaries** are bodies of water in which freshwater from rivers mixes with salt water from the sea. Most estuaries at temperate latitudes are **salt marshes**, shallow wetlands that are flooded with salt water during high tides. Estuaries and salt marshes are highly productive

ecosystems that play an important role in the life cycle of many fish and marine organisms. The rivers that flow into estuaries carry nutrients and sediment from upstream, and these create perfect conditions for salt-tolerant plant growth. The dense plant growth found in salt marshes provides important habitat for birds, crabs, shrimp, clams, and oysters, and it also serves as spawning grounds for many species of open ocean fish. In addition, salt marshes (like freshwater wetlands) help filter pollution from the water, and they play an important role in stabilizing coastal shorelines against storm surges. Unfortunately, estuaries and salt marshes have been heavily affected by coastal property development, the construction of shipping channels, and oil and gas operations, leaving some coastal areas more vulnerable than before to flooding.

### ***Mangrove Forests***

In tropical and subtropical regions, **mangrove forests** are a more common feature in estuaries than salt marshes. Mangroves are a variety of tree that can grow in brackish, or slightly salty, water found in estuaries. Mangrove roots grow both upward out of the water to absorb oxygen and downward to support the tree in the sediment below the surface of the water. Like salt marshes, mangrove forests are highly productive ecosystems that support a vast array of birds, fish, shellfish, and other organisms. The dense and tangled root systems of mangrove forests provide safe spaces for juvenile fish to spawn and grow before moving to the open ocean.

Mangrove forests are also important for stabilizing coastal shorelines and absorbing heavy waves and floodwaters. After a massive tsunami struck southern Asia and killed over 200,000 people in 2004, research showed that coastal areas with healthy and intact mangrove forests experienced less severe destruction than those areas where mangrove forests did not exist or had been cleared (Kinver, 2005). Unfortunately, over half of the world's mangrove forests have already been destroyed to make way for fish farming and aquaculture, coastal development, or firewood and timber. In areas where mangrove forests have been cleared, coastal areas are at increased risk of flooding, and nearby fisheries have seen declines in productivity.



*Photodisc/DigitalVision/Getty Images*



*aiisha5/iStock /Getty Images Plus*

**Estuaries (left) and mangrove forests (right) are two critical ecosystems in the intertidal zone.**

## Benthic Zone

The **benthic zone** refers to the region at the bottom or lowest level of a body of water. The ocean benthic zone extends all the way from the shallow sands of the intertidal zone, less than a meter below the surface, to the deepest ocean trenches of the Pacific Ocean, 11,000 meters (36,200 feet, or almost 7 miles) deep. The most productive regions of the benthic zone are found in relatively shallow waters where light is available. And among the most important ecosystems found in this shallow portion of the benthic zone are seagrass beds, kelp forests, and coral reefs.

### *Seagrass Beds*

Seagrasses are underwater plants adapted to submersion in salt water. Large areas of seagrass, or seagrass beds, grow up to 10 meters (32 feet) below the surface, where there is still enough light for them to photosynthesize. Common seagrass varieties include eelgrass, manatee grass, turtle grass, and shoal grass. Seagrass beds help stabilize coastal ecosystems, absorb wave energy, and reduce erosion. They are also an important habitat and food source for shorebirds, sea turtles, manatees, and a variety of fish that “graze” on the seagrass in the same way that a land-based animal might graze on prairie grasses.

### *Kelp Forests*

Kelp is a type of brown algae or seaweed that can grow in dense stands known as kelp forests. Kelp is more commonly found in cooler, shallow waters and along rocky coastal areas. Kelp grows from the floor of the ocean in long strands toward the surface, with some kelp reaching up to 60 meters (200 feet) in length. The dense vegetation found in kelp forests helps absorb wave energy and reduce coastal erosion. This vegetation also provides a perfect habitat and food source for many varieties of fish, shellfish, crustaceans, and other organisms.



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*Windzepher/iStock/Getty Images Plus*

**Seagrass beds and kelp forests are two productive ecosystems where sunlight reaches the benthic zone.**

In recent years marine scientists have uncovered interesting connections between the health of kelp forests and populations of sea urchins and sea otters. Warmer ocean waters have led to rapid growth in the populations of sea urchins, and these creatures love to graze on kelp. In some areas kelp forests have been grazed to almost nothing by rising numbers of sea urchins, a type of underwater deforestation. However, recall from Chapter 2 that sea otters prey on sea urchins, and in places where healthy populations of sea otters exist, the kelp forests are in better condition. This relationship between the health of the kelp forests and the status of the sea otter population is one reason why otters are considered a keystone species in these ecosystems.

### Learn More: Kelp Forests

This short video allows you to take a virtual dive through a kelp forest off of the California coast.

- <https://www.calacademy.org/educators/take-a-virtual-dive-in-a-kelp-forest>

### *Coral Reefs*

Corals are small invertebrates (animals lacking a backbone) that are related to jellyfish and sea anemones. Corals attach themselves to rocks or other underwater surfaces and build a limestone shell around themselves for protection, using minerals available in the water.

Corals feed in one of two ways. First, they live in a symbiotic relationship with algae known as *zooxanthellae* that inhabit their tissues and produce food through photosynthesis. It is the different varieties of *zooxanthellae* algae that give corals their brilliant colors. Second, corals use tiny stinging tentacles to paralyze plankton and other small organisms that drift by and feed on the plankton. As corals die, the tiny shells they built for themselves remain, and a new generation of corals builds on top of these. Over time, these accumulated layers of limestone shells form entire reefs that are home to coral colonies containing millions of individual corals.

Like kelp forests, seagrass beds, and mangrove forests, the physical structures of coral reefs absorb wave energy and help reduce coastal erosion and flooding. Coral reefs are also the most biodiverse of all marine ecosystems, equivalent in some ways to the tropical rain forests on land. Coral reefs are home to hundreds of fish species and other organisms, and they are a critical habitat and place of protection for juvenile fish. In addition, coral reef ecosystems are an important contributor to local tourism in many regions.

Despite providing all these ecosystem functions and services, coral reefs are under threat worldwide from a number of human-induced factors. Destructive fishing practices, including the use of cyanide and dynamite to stun or blast fish out of the water, are destroying coral reefs in some regions of Southeast Asia. Ocean pollution smothers coral reefs. And perhaps of most concern, warmer ocean waters caused by global climate change are leading to coral bleaching and the large-scale die-off of corals around the world. These and other causes of coral reef decline will be discussed further later in the chapter.

## Pelagic Zone

The **pelagic zone** refers to everything else in the ocean that is not a part of the intertidal or benthic zones; namely, all the oceans' open waters. The vast expanse of the pelagic zone is usually further subdivided into horizontal zones by depth and degree of light penetration, because light and nutrient availability are the key determinants of biological productivity in these waters. Generally, the upper 200 meters (650 feet) of the ocean is classified as the **photic zone** because light from the sun can reach that level. Everything below 200 meters in depth, fully 94% of all ocean water, is classified as the **aphotic zone** because it is usually beyond the reach of light from the surface.

Phytoplankton found in the pelagic zone of the world's oceans are the most important producers of the sea, and most primary production in the oceans occurs in regions favorable to the growth of phytoplankton. Because producers like phytoplankton need sunlight to photosynthesize, virtually all primary production occurs in the photic zone. In addition, because phytoplankton, like other plants and algae, need nutrients, primary production is even higher in the photic zone near upwelling currents and estuaries that receive a steady input of nutrients. Overall, this means that biological productivity and diversity in the pelagic zone is highly variable across oceans, depending on location and light and nutrient levels. And because phytoplankton form the base of the marine food web, their abundance in surface waters near upwelling currents and estuaries means that most marine life will be located there as well.

Below the photic zone, in the vast depths of the ocean aphotic zone known as the oceanic province or the deep sea, living conditions become more extreme, and life forms can become bizarre. Environmental conditions in these waters include extremely high pressures, a complete absence of light, low oxygen levels, and very cold water temperatures. Despite these extremes, an array of life has evolved and adapted to survive in these conditions. Most aquatic life in the deep sea relies on marine snow for food and energy. Other organisms have adapted to living around hydrothermal vents on the ocean floor that pump out mineral-rich heated water from below the surface.

Some of the strangest and most remarkable creatures in the ocean make the deep sea their home. This includes spider crabs that can span over 5 meters (16 feet) from claw to claw and weigh up to 19 kilograms (42 pounds), deep sea dragonfish and anglerfish that produce their own light to lure prey toward them, and sea creatures with names that fit their bizarre appearance: the Pacific viperfish, the fangtooth fish, the Atlantic wolffish, the terrible-claw lobster, the goblin shark, the vampire squid, and the colossal squid.

## Reviewing Marine Ecosystem Functions and Services

Oceans are essential to human survival. As discussed earlier in this chapter, from 50% to 85% of the oxygen in the atmosphere is produced by marine phytoplankton. Oceans provide up to 40% of the precipitation to land surfaces. Without ocean currents, the global climate would be one of extremes. Most midlatitude and upper latitude regions, including much of the United States, would be frigid and uninhabitable, and most places near the equator would be too hot for human settlement. Marine ecosystems like coral reefs, kelp forests, salt marshes, seagrass beds, and mangrove forests reduce wave energy, slow erosion and flooding, remove pollutants from the water, and cycle nutrients.

One ecosystem service we have yet to discuss has to do with the role of phytoplankton in the carbon cycle. When phytoplankton photosynthesize, they absorb carbon dioxide from the atmosphere. As phytoplankton die or get eaten by other organisms, that carbon gets transported to the deep sea as part of marine snow, and some of that carbon ends up becoming part of deep sea marine sediments, where it is stored for centuries. In this way oceans act as a biological pump that transfers some carbon dioxide (a greenhouse gas that can contribute to global warming) from the atmosphere to the bottom of the ocean.

Beyond these environmental functions and services, ocean and marine ecosystems generate a range of direct economic benefits. For starters, commercial fisheries employ tens of millions of people worldwide and generate hundreds of billions of dollars in revenue each year. Likewise, coastal and marine tourism is a major industry in many countries, employing a similar number of people and generating even more revenue than commercial fisheries. The world's oceans provide convenient shipping lanes for global commerce and transportation. And the oceans are also an increasingly important source of pharmaceutical products and compounds that can treat illness and disease. Interest in marine sources of medicinal products has led to the establishment of an entire field known as marine pharmacology.

While it's challenging to find the precise economic value of the oceans' products and services, in 2015 the World Wide Fund for Nature attempted to do just that. The group's research suggests that a *conservative* estimate of the "asset value" of the world's oceans is \$24 trillion and that these assets yield goods and services to humans with a value of at least \$2.5 trillion every year (World Wide Fund for Nature, 2015). Much of these goods and services take the form of seafood harvests, tourism revenue, the value of shipping lanes, and erosion prevention provided by coastal ecosystems. In other words, this \$2.5 trillion estimate does not include environmental services: oxygen production, water cycling, and climate regulation.

The remainder of this chapter will review some of the major ways we are threatening or destroying these ecosystems that are so critical to our economy and well-being—and some of the steps being taken to mitigate that destruction.

## 6.3 Ocean Pollution

Perhaps because oceans seem far away and out of sight, we engage in many activities that harm the health of the oceans and destroy critical marine ecosystems. This section will review the most basic threat: pollution. Given that there are so many different ways we pollute the ocean, the discussion is broken down into issues of nutrient pollution, plastic pollution, oil spill pollution, and other forms of ocean pollution.

### Nutrient Pollution

Nutrient pollution refers to the impact of excess nutrients on marine ecosystems, which we have discussed to some extent in previous chapters. When fertilizers run off of farm fields, golf courses, and suburban lawns, or when nutrient-rich animal waste flows into nearby streams and rivers from animal feeding operations, large quantities of nitrogen and phosphorous are

introduced to these ecosystems. This eutrophication leads to rapid growth of phytoplankton and potentially sudden drops in dissolved oxygen levels, a condition known as hypoxia. Hypoxia or hypoxic conditions can lead to the death and displacement of a wide variety of marine life and result in what is known as an aquatic dead zone, as discussed in the case study in Chapter 2.



Justin Smith/iStock/Getty Images Plus

A specific type of algal bloom that can be very destructive and dangerous to marine life and even humans is commonly known as a “red tide.” Red tides are caused by an explosion of growth in a specific type of algae known as *dinoflagellates*, and when millions of these algae grow in a specific location, they can change the color of the water to red, pink, orange, or yellow. Dinoflagellates contain a toxin that can affect the nervous systems of marine animals, which is why marine scientists prefer to call these outbreaks *harmful algal blooms*, or HABs. In 2018 massive HABs broke out along Florida’s Gulf coast, resulting in the death of hundreds of sea turtles, manatees, and dolphins, as well as tens of thousands of fish. As dead fish and marine mammals washed up onshore, the neurotoxin that caused their deaths had the potential to become airborne and sicken people. As a result, long stretches of beach were closed, and the state lost billions of dollars in tourism revenue. While HABs do occur naturally, they become more frequent and large scale because of nutrient pollution from human activities.

**Algae bloom in a wetland area, which has caused the water to look red and murky. These sorts of harmful algal blooms (HABs) are harmful to both marine and human life.**

The frequency and intensity of eutrophication, dead zones, and harmful algal blooms can be reduced in a number of ways. The key is to reduce the rate of nutrient pollution that reaches the ocean. More careful application of fertilizers to farm fields, golf courses, and suburban lawns will reduce nitrogen and phosphorus runoff. Farmers could also make greater use of riparian buffers that absorb nutrients before they can enter streams and rivers. Likewise, better management of waste products from animal feeding operations can reduce nutrient runoff from this source. Farther downstream, restoration and protection of coastal wetlands and salt marshes can go a long way toward reducing nutrient pollution of the oceans, since these ecosystems soak up excess nutrients from the waters that pass through them. Lastly, some areas are turning to shellfish like oysters and mussels to reduce nutrient pollution of nearby waters. For example, an effort known as the [Billion Oyster Project](#) is restoring oyster populations to the polluted waters of New York Harbor. Oysters filter up to 190 liters (50 gallons) of water a day, and this project aims to establish enough oyster beds to filter all the water in New York Harbor every few days.

## Plastic Pollution

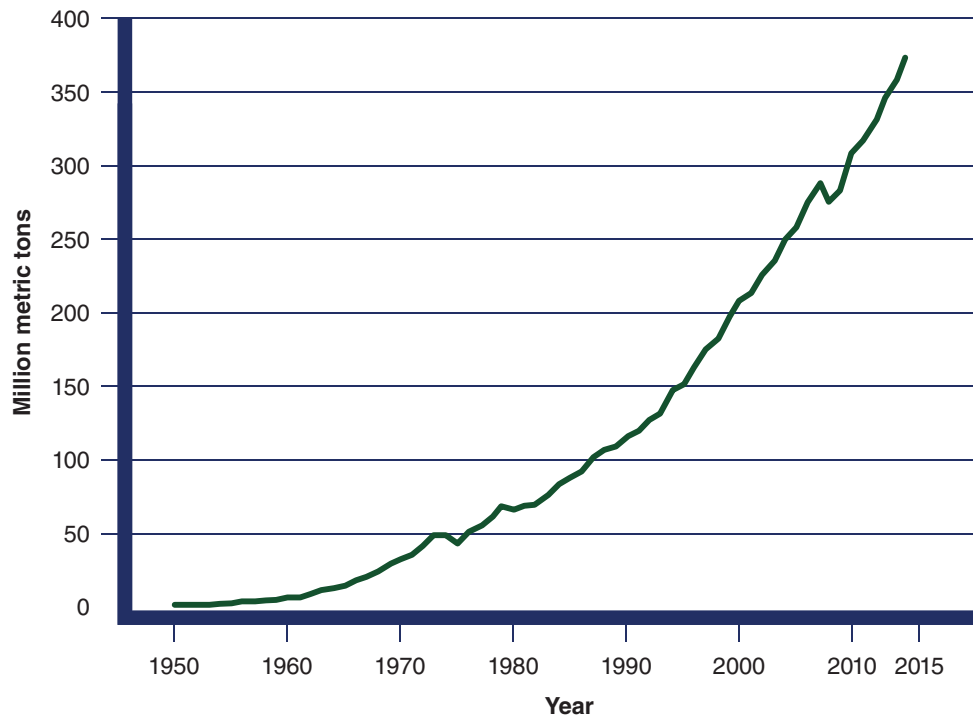
Plastic pollution is a relatively new problem. Plastics did not come into widespread production and use until after World War II, but today they are seemingly everywhere and a part of almost every product we use in our everyday lives. Plastics are light, inexpensive and easy

to produce, and convenient for manufacturers and consumers alike. However, some of those same benefits are now contributing to making plastics a major pollution problem on land, in the sea, and in just about every region of the world.

Researchers estimate that in the past 60 to 70 years, *8.3 billion metric tons* of plastics have been produced globally (see Figure 6.4). Of that total, roughly 5 billion metric tons has either been sent to landfills or is still located somewhere else in the environment (Geyer, Jambeck, & Law, 2017). From this plastic waste, it's estimated that roughly 8 million metric tons enters the oceans from land surfaces each year (Jambeck et al., 2015).

## Figure 6.4: Global plastic production

Global plastic production and use exploded after World War II.



Source: Adapted from "FAQs on Plastics," by H. Ritchie, 2018 (<https://ourworldindata.org/faq-on-plastics>). CC BY.

And the problem of plastic pollution is not going to go away anytime soon. We are still producing an estimated 310 million metric tons of plastic every year, with roughly 82 million metric tons going to plastic packaging alone. Most plastic packaging is designed specifically for a single use and then disposal, with limited or no options for recycling or reuse, so much of this plastic will continue to enter landfills or the environment. The most common single-use items made of plastic that are found during ocean and beach cleanups are cigarette butts (which contain a small plastic filter), food wrappers, beverage bottles, bottle caps, grocery bags, straws, lids, and take-out boxes. We produce over 6 trillion cigarettes and 5 trillion plastic grocery bags every year.

### ***Impact on Marine and Human Life***

Plastic pollution is such a serious problem because plastic wastes do not biodegrade in the same way that organic wastes do. Instead, they undergo a process known as **photodegradation**, in which materials are broken down into smaller pieces by sunlight. Because plastic that is in the water is not as directly exposed to sunlight, plastic waste in the oceans and other bodies of water photodegrades more slowly than on land, taking as long as 500 to 1,000 years to fully break down. To make matters worse, since plastics do break down into smaller pieces, they are mistaken as food by fish and marine mammals. And because most plastic is made using toxic materials, these toxins also become part of what is ingested.

The National Oceanic and Atmospheric Administration has identified three main ways in which ocean plastic pollution is impacting marine life. First, ocean plastic pollution often consists of plastic fishing nets, ropes, and other debris from fishing fleets. Marine life, especially mammals like sea turtles, whales, and dolphins, can become entangled in this debris and either suffocate or drown.

Second, marine animals often mistake plastic pollution for food and ingest it. This plastic waste can accumulate in their stomachs and create intestinal blockages and other problems. A recent study by Australian scientists found that over half of all sea turtles around the world have ingested plastic debris and that just a small amount of ingested plastic can significantly increase the risk of death for these creatures (Weintraub, 2018). To make matters worse, the toxins used to make most plastic thereby enter the food chain and can amass in the tissues of marine life higher up on the food chain. For example, Styrofoam products contain carcinogenic chemicals like styrene and benzene. Scientists are now referring to the trillions of tiny pieces of plastic building up in oceans, rivers, lakes, and streams as **microplastics**, and they are worried that these microplastics are so pervasive that they might now threaten human health. This is because we could be ingesting this material when we eat fish and even when we drink water drawn from surface waters. (The *Close to Home* feature box explores one type of microplastic found in clothing.)

Third, some species can use plastic debris and ocean currents to move from one place to the other, and this can introduce nonnative invasive species to new ecosystems. Overall, the UN estimates that plastic pollution of the world's oceans imposes economic costs of at least \$13 billion every year, including cleanup costs and lost tourism revenue (United Nations Environment Programme, 2014).



Ian Dyball/iStock/Getty Images Plus



Erlantz Pérez Rodríguez/iStock/Getty Images Plus

**Pollution is devastating to marine life. They can become entangled, as this seal (left), or they might ingest some of the trillions of microplastics (right).**

## Close to Home: Examining Choices Around Clothing

You might be surprised to learn that some forms of microplastic pollution come from the clothing we wear on a daily basis. These plastic microfibers represent a new frontier in environmental research, and recent findings suggest that they make up a significant fraction of ocean plastic pollution.

Clothing materials come in a variety of forms. Natural fibers like wool, linen, and cotton come from plants and animals, and unless they are treated with harsh chemicals, they do not usually pose a major environmental concern when released into the environment. Over the past several decades, however, human-made fabrics have become far more common. Petroleum-based synthetic fibers like polyester, spandex, and nylon now make up about 60% of clothing worldwide (Resnick, 2019).

Like most clothing materials, synthetic fabrics wear out over time. As they age, fibers begin to fray and break off into smaller pieces called microfibers. When people wash their clothing, these plastic particles are shed in large quantities into the washing machine's wastewater, and the particles are too small to be captured by most sewage treatment facilities. Many microfibers find their way into rivers and oceans that transport them all over the world. Researchers have found microfibers throughout rivers, lakes, and oceans; in the sand on remote islands; in the air; and even inside the fish and shellfish that we eat. Because salt water is sometimes used to make salt, microfibers can be found there too, and because treated sewage is sometimes used as fertilizer, microfibers can be found in our soil. Plastic microfibers are pretty much everywhere!

Unlike natural fibers, plastic microfibers do not break down very easily in the environment, and some animals mistake them for food. Consuming microfibers can result in nutritional deficiencies, digestive problems, and even death for smaller creatures like zooplankton, shellfish, and earthworms. Microfibers can also transmit toxins into the soft tissue of larger organisms like fish, seabirds, and filter-feeding whales. Many of the risks associated with microfiber pollution are still unknown, but the more we learn, the more cause we have to be concerned.

Take a look at a few of your clothing tags and see if your wardrobe is a source of microfiber pollution. If you find materials like nylon, polyester, spandex, acrylic, and acetate, take a moment to develop some strategies for reducing your individual microfiber emissions. Are there lifestyle choices you could make to reduce microfiber pollution and still live a happy and healthy life? Are there more environmentally friendly choices that you can make as a consumer? Are there more technological or systemic solutions that might be outside of your immediate control? What kinds of actions do you think will be most effective when tackling this environmental challenge?

If you don't have all the answers, you are not alone. The plastic microfiber problem is new to most researchers, engineers, and city planners. We are only just beginning to understand the possible impacts of this form of plastic pollution, and we need creative minds to develop new solutions.



*DeAgostini/SuperStock*

**Nylon microfiber viewed under a microscope.**

Plastic pollution in the oceans tends to get concentrated in certain areas because of the circular flow of water caused by gyres. This whirlpool effect has concentrated volumes of plastic debris and waste into what are known as “garbage patches.” The most well known of these garbage patches has come to be called the **Great Pacific Garbage Patch (GPGP)**.

In reality, the GPGP refers to two separate garbage patches in the North Pacific Ocean, one near Japan in the western Pacific and the other between Hawaii and California in the eastern Pacific. The eastern portion of the GPGP was recently the subject of a scientific expedition that set out to determine the volume, scope, and composition of the plastic pollution found there. This research found that the eastern part of the GPGP extended across an area of ocean 1.6 million square kilometers (617,763 square miles) in size, an area twice the size of Texas. It also estimated that there were over 1.8 trillion pieces of plastic in the garbage patch, with a total weight of 80,000 metric tons. In terms of the number of pieces, most of this plastic waste was in the form of microplastics smaller than 5 millimeters in size (roughly the size of a letter on a keyboard). However, when measured by weight, 46% of the garbage patch consisted of discarded fishing nets and other gear (Ocean Cleanup, n.d.).

### Learn More: An Island of Plastic Waste

In May 2019 a group of Australian marine scientists led by research scientist Jennifer Lavers published the results of a study they conducted on plastic pollution in the Cocos Islands of Australia. The Cocos Islands are located in the remote Indian Ocean, far off the northwestern coast of Australia and far from any commercial or population centers. The islands are billed as Australia’s “last unspoilt paradise” (Cocos Keeling Islands, 2019, para. 1), and so it came as a surprise when the researchers discovered hundreds of millions of pieces of plastic waste on the beaches of Cocos. The final tally of plastic waste from their survey was staggering: 373,000 plastic toothbrushes, 975,000 plastic flip-flops, and an estimated 414 million pieces of plastic waste weighing a total of 238 metric tons. Equally amazing was that the plastic waste was not just on the surface of the beach but got thicker as the scientists dug deeper. You can learn more about this research and what it tells us about plastic pollution, ocean currents, and its impact on marine biodiversity and wildlife by visiting these links:

- <https://www.nature.com/articles/s41598-019-43375-4>
- <https://naturecoevocommunity.nature.com/users/262039-jennifer-lavers/posts/49172-what-remote-islands-can-tell-us-about-consumption-community-and-the-future-of-clean-ups>
- <https://www.youtube.com/watch?v=fTGmpVUXwF4>

### *Efforts to Reduce Plastic Pollution*

Given that plastic pollution of the world’s oceans is now being measured in billions of pounds and trillions of pieces, it would seem like an impossible task to try to clean it up. However, that did not stop a young inventor named Boyan Slat, who in 2012 first proposed the idea of a floating device to collect plastic waste from the oceans. Slat went on to form an organization known as Ocean Cleanup, which raised millions of dollars to develop and test a 600-meter-long (2,000-foot-long) buoy device to “sweep the sea” of plastic debris. Unfortunately, early

tests of this device that occurred in areas of the GPGP in late 2018 resulted in a complete failure. Rough seas and mechanical problems prevented the sea sweeper from collecting any measurable plastic waste, and the device is currently undergoing modifications for further testing.

Even before the initial failure of the sea sweeper project, most marine scientists agreed that ocean plastic pollution could realistically only be addressed through prevention. This includes managing plastic waste on land to prevent it from ever reaching the oceans in the first place, as well as improving plastic recycling, designing more plastic products to be reused, using more biodegradable plastics, and substituting nonplastic packaging material. Even outright bans on some types of plastic material—especially single-use packaging, bags, and straws—are becoming more common.

## Oil Spill Pollution

On April 20, 2010, there was a massive explosion on the Deepwater Horizon oil platform in the Gulf of Mexico, 68 kilometers (42 miles) off the coast of Louisiana. The explosion killed 11 workers and ripped open underwater piping, which began pouring thousands of gallons of oil into the Gulf. It took almost 3 months to cap the pipe and control the flow of oil, and by that time an estimated 3.2 million barrels (134 million gallons) of oil had leaked into the Gulf. As a result, hundreds of thousands of seabirds died, the Gulf shrimp fishery closed, over 1,600 kilometers (almost 1,000 miles) of beach from Texas to Florida were fouled with oil slicks, and fish and marine mammal deaths increased. The longer term impacts of the oil spill are more difficult to determine. Recent studies have shown that oil residues from the spill are still altering deep sea life in the area around the site of the disaster (Girard & Fisher, 2018; Biedron & Evans, 2016). Other research is ongoing to determine both the fate and effects of the spilled oil and to see if any of the chemical dispersants used to clean up the spill are having harmful impacts on wildlife and ecosystems in the Gulf.



*Coast Guard Public/SuperStock*

**The Deepwater Horizon oil platform explosion resulted in an estimated 3.2 million barrels of oil spilling into the Gulf of Mexico.**

Twenty-one years before the Deepwater Horizon oil spill in the Gulf of Mexico, the *Exxon Valdez* oil tanker ran aground in Prince William Sound in Alaska. At the time, the *Exxon Valdez* oil spill was the worst of its kind in the United States, and it had devastating impacts on wildlife, commercial fisheries, and native Alaskan communities in the area. Other large oil spills from oil platform disasters or tanker accidents have also had devastating impacts on marine life, commercial fisheries, and coastal tourism. Fortunately, the number of major oil spills from oil tankers has been going down over the years, due to improved safety features and designs. The biggest impact has come from the shift to double-hull tankers that have an outer and inner plate separating oil from the water.

While oil spill pollution from oil tanker disasters is on the decline, it turns out that these disasters are not even the largest source of oil pollution in the world's oceans. Instead, the greatest amount of oil pollution comes from routine, and often intentional, dumping of smaller amounts of oil into the water. Thousands of commercial ships and even larger numbers of small recreational craft constantly leak oil into the ocean. Likewise, millions of cars and trucks on land are constantly leaking oil that can run off of road and parking lot surfaces and make its way to the sea. In addition, some individuals dump motor oil from oil changes into storm drains, and this oil is washed into nearby bodies of water and to the sea. All these small inputs of oil add up and can have more subtle but still significant impacts on wildlife relative to the major oil spills that receive most of our attention.

A final area of concern regarding oil spills involves pipelines that run under or near bodies of water. For example, the Trans Mountain oil pipeline in Canada carries crude oil from tar sand deposits in Alberta to a port area in British Columbia, 1,150 kilometers (715 miles) away. There the crude oil is refined and shipped to China and other oil-importing nations in Asia. A proposed expansion of this pipeline has resulted in fierce opposition from environmental groups, commercial fishing organizations, and First Nation tribes. The waters and shorelines around the Trans Mountain marine terminal are critical areas of habitat for a variety of whale species, chinook salmon, and Pacific herring, as well as nesting and breeding grounds for millions of seabirds. A pipeline rupture or oil tanker accident and spill in or near these habitats could have devastating effects. For now, however, the Canadian government is promising to move ahead with the proposed expansion of the pipeline while ensuring that safeguards will be put in place to minimize the impact of any oil spill disaster.

## Other Forms of Marine Pollution

There are other forms of ocean and marine pollution that get less attention but are important to consider.

### *Noise Pollution*

While being underwater may seem quiet to our ears, the issue of **ocean noise pollution** has gained increasing attention from marine scientists in recent years. Because whales, dolphins, fish, and other marine life use sound to communicate, find food, and navigate, human activities that create underwater noise can be highly disruptive to these creatures.

Among the major causes of ocean noise pollution are commercial ship traffic, high-intensity sonar, and high-powered underwater air guns used for offshore oil and gas exploration. There are roughly 60,000 commercial oil tankers and container ships that ply the world's oceans and waterways every day, creating underwater noise with their propellers—another reason opponents are concerned about the Trans Mountain oil pipeline expansion. Likewise, the U.S. Navy and other major power navies use high-intensity sonar to navigate and to detect underwater objects such as submarines. The sound waves created by high-intensity sonar have been shown to drive whales and other marine mammals away from an area (Parsons, 2017; Bernaldo de Quirós et al., 2019). In some cases the noise pollution created by high-intensity sonar has been so bad that large numbers of whales and dolphins have beached themselves and ended up dying to get away from the sounds.

However, it is the growing use of high-powered underwater air guns or seismic air guns that has been getting the most attention in recent years. Air guns are used on giant ships that criss-cross ocean waters in a grid pattern for oil and gas exploration. A single ship might be mounted with up to 48 air guns, with each gun blasting pressurized air into the water beneath it every 10 to 12 seconds for weeks or months at a time. The sound waves from the air blasts bounce off the ocean floor and back to the surface, where other equipment on the ship records them and uses this information to create maps of where oil and gas might be located. The sound from air guns can reach up to 260 decibels underwater, equivalent to 200 decibels aboveground. By comparison, the launch of the Space Shuttle created a sound of about 160 decibels for people nearby. The sound from air gun blasts can also travel long distances, as much as 4,000 kilometers (2,500 miles) in some cases. Overall, marine scientists have described the sheer intensity, frequency, and range of noise pollution from seismic air guns as creating a “living hell” for underwater marine life (Robbins, 2019). Recent research has even revealed that blasts from seismic air guns can kill large numbers of tiny zooplankton near the base of many marine food webs (McCauley et al., 2017; Tibbetts, 2018). In addition, research conducted in Norway found that commercial fish catches decline by up to 80% in areas where seismic air guns are being used for oil and gas exploration (Huelsenbeck & Wood, 2013).

### ***Atmospheric Deposition***

Another invisible form of ocean pollution actually starts out as air pollution. Industrial activities and energy consumption (such as burning coal) can put heavy metals and toxins like mercury and lead into the atmosphere. These air pollutants are carried by winds over oceans and other bodies of water, where they can wash out and fall to the surface when it rains. Such **atmospheric deposition** of heavy metals and other pollutants can have slow-moving and almost imperceptible impacts on marine food webs and eventually even affect human health.

Toxins like mercury and lead can be absorbed by phytoplankton and zooplankton, which form the base of many marine food webs. When larger marine animals consume large quantities of these plankton, they ingest more of the toxins, and when even larger marine animals consume those marine animals, the concentrations of toxins can increase even further. Recall that this increasing concentration of toxins at higher levels of the food chain is known as *biomagnification* (see Chapter 4). **Bioaccumulation** refers to the buildup of toxins in an individual organism over time. Because of biomagnification and bioaccumulation, levels of mercury and other toxins in some species of fish near the top of the food chain are so high that they pose a health risk to humans.

### ***Sunscreen***

Finally, a somewhat novel form of ocean pollution is sunscreen. In early February 2019 the City Commission of Key West, Florida, voted 6–1 to ban sales of sunscreen that contain chemicals (mainly oxybenzone and octinoxate) believed to be harmful to coral reefs. Key West joins the state of Hawaii and the small country of Palau in banning sales of certain types of sunscreen, which can wash off of swimmers and snorkelers and come in contact with coral reefs. The chemicals lead to bleaching and other damage to the corals. Marine scientists and environmental groups concerned about this issue point to “coral safe sunscreens,” which do not contain these harmful chemicals, and encourage people to use these instead.

### Learn More: Are Coral Safe Sunscreens for Real?

Recent efforts to ban the sale of sunscreens that contain oxybenzone and octinoxate have led to the development and marketing of what are being labeled as “coral safe” and “ocean safe” versions. While this is a move in the right direction, a 2019 analysis by *Consumer Reports* magazine found that even these supposedly eco-friendly sunscreens might still be harmful to coral and other marine life. *Consumer Reports* recommends wearing UPF (ultraviolet protection factor) clothing as a way to cut down on the amount of exposed skin that needs to be treated with sunscreen. You can learn more about this issue and the findings of the *Consumer Reports* research here:

- <https://www.consumerreports.org/sunscreens/the-truth-about-reef-safe-sunscreen>

## 6.4 Other Major Threats to Ocean and Marine Ecosystems

Besides the direct impact on marine ecosystems of various forms of pollution, there are a number of indirect threats to our oceans that we need to consider. We'll start with the physical and chemical changes to oceans and marine ecosystems due to climate change. This is followed by an examination of the problem of overfishing and the ripple effects this has throughout marine food webs. Lastly, we'll consider issues of marine and coastal habitat destruction and invasive species.

### Climate Change

Over the past 200 years, as human use of fossil fuels like oil, coal, and natural gas has increased, so too have atmospheric concentrations of carbon dioxide. The combustion of fossil fuels releases CO<sub>2</sub> to the atmosphere, and as a result atmospheric concentrations of this gas have risen from 280 ppm around the year 1800 to over 400 ppm today.

Because CO<sub>2</sub> is a greenhouse gas, increased atmospheric concentrations have resulted in warming of the planet, something we will explore in much more detail in Chapter 8. This global warming has also resulted in warming of the oceans, which is negatively affecting marine life and biodiversity. In addition, higher atmospheric concentrations of CO<sub>2</sub> are actually changing the chemistry of ocean waters, with equally serious impacts. This *twin threat* to oceans from rising CO<sub>2</sub> levels is the subject of this section.

### Ocean Warming

Greenhouse gases like carbon dioxide and methane trap and hold heat in the Earth's atmosphere. The increase in atmospheric concentrations of CO<sub>2</sub> and other greenhouse gases since the start of the Industrial Revolution has already resulted in warming of the planet's surface by roughly 1 degree Celsius (about 1.8 degrees Fahrenheit). But it turns out that this surface warming would be much worse were it not for the fact that the oceans have been absorbing

over 90% of the additional heat caused by human greenhouse gas emissions. While this absorption has helped slow the rate of global warming, it is having profound and destructive effects on the world's oceans. Each year the oceans become warmer than the year before: As of this writing, 2018 was the warmest year on record for the world's oceans; 2019 data was not yet available. Warmer oceans mean increased sea level rise and coastal flooding, as well as more powerful hurricanes and coastal storms.

Warmer ocean waters can also be very destructive to coral reef ecosystems. Recall that corals are actually tiny invertebrate animals that attach themselves to underwater surfaces and build a calcium carbonate shell for protection. Also recall that these coral animals live in a symbiotic relationship with colorful algae known as zooxanthellae. The zooxanthellae can produce food through photosynthesis and share some of that food with the coral animals that give them a home. Marine scientists now know that warmer ocean waters cause coral animals to expel the zooxanthellae algae, resulting in *coral bleaching*. **Coral bleaching** is so named because of the whitening that occurs due to the loss of the vibrant zooxanthellae, but it's not just about color. The photosynthetic actions of the zooxanthellae algae provide corals with as much as 90% of their energy needs, and when they are expelled the corals can weaken and die.

Recent assessments of Australia's Great Barrier Reef—the largest coral reef ecosystem in the world—have determined that 90% of corals there show evidence of bleaching (Kahn, 2016). Marine scientists who study the Great Barrier Reef are now predicting a massive coral die-off and planetary catastrophe. In other parts of the world, there is evidence that even if coral bleaching doesn't kill coral organisms outright, it weakens them and lowers their ability to fight off disease. As much as 80% of corals in the Caribbean, weakened by coral bleaching, have been wiped out from “white band disease,” and a number of important coral species are nearing extinction.



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Gerald Nowak/Westend61/SuperStock

**Warming ocean temperatures are detrimental to coral reefs across the globe. Here two photos show different coral reefs in Indonesia. One reef is thriving (left), while the other is now dead (right).**

### ***Ocean Acidification***

Corals and a variety of other marine organisms are also being negatively affected by a problem known as **ocean acidification**, whereby the ocean becomes overly acidic because of too much CO<sub>2</sub>.

Recall that an important ecosystem service provided by oceans is that they act like a biological pump, taking excess carbon dioxide from the atmosphere and transferring it to sediments at the bottom of the ocean. Scientists now estimate that the oceans are absorbing as much as one third of excess CO<sub>2</sub> emissions from fossil fuel combustion. While this seems like it would be a good thing and would slow global warming, the absorption of too much CO<sub>2</sub> actually alters the basic chemistry of ocean waters.

When CO<sub>2</sub> combines with ocean water, it produces carbonic acid (H<sub>2</sub>CO<sub>3</sub>), increasing the acidity of the water. This process also reduces the level of carbonate ions in the water, and carbonate ions are used by marine organisms like corals, oysters, and even some types of phytoplankton to produce calcium carbonate for their shells. Lower levels of carbonate ions can slow the rate of coral growth and weaken shells of marine organisms like oysters, mussels, crabs, and sea snails.

Worldwide measurements of ocean chemistry show that oceans are warmer and more acidic now than at any time in the past 400,000 years. While many marine organisms might be able to adapt to slow-moving and slight changes in ocean temperature and chemistry, the rate of change is currently too much for some to adjust to. The average acidity of the world's oceans has increased 30% since 1800, and this fundamental change in ocean chemistry is adding to the stress caused by warming and pollution. There is even growing evidence that both ocean warming and acidification are reducing populations of phytoplankton, which will in turn affect the higher echelons of the marine food web (Smithsonian Ocean Portal, n.d.).

While the most obvious answer to ocean warming and acidification is to reduce combustion of fossil fuels and CO<sub>2</sub> emissions, scientists are also looking at other ways to deal with these challenges. Marine scientists in the Pacific Northwest are looking at whether marine plants like kelp and seagrass can keep the water from getting too acidic for oysters and other marine organisms. Because these marine plants use CO<sub>2</sub> when they photosynthesize, the hope is that more of them will prevent CO<sub>2</sub> from being converted to carbonic acid.

Likewise, marine scientists in Australia and Hawaii are scrambling to collect coral sperm from coral reef organisms. Worried that coral bleaching and acidification will wipe out coral reef ecosystems, these scientists are collecting the sperm and freezing it in coral sperm banks. The frozen sperm could be used to repopulate coral reefs in the future if conditions improve, and it is also being used to help breed “super corals” that can withstand warmer and more acidic ocean waters.

### Learn More: Coral Reefs

Coral reefs are truly amazing ecosystems. You can learn more about them and the threats to them at these sites.

- <https://ocean.si.edu/ecosystems/coral-reefs>
- <https://www.virtualreef.org.au>
- <https://oceanservice.noaa.gov/ocean/corals>

## Overfishing

The Food and Agriculture Organization (FAO) of the United Nations (2018b) estimates that fish accounts for about 17% of worldwide animal protein consumption. The FAO also estimates that over 50 million people are employed in commercial fisheries around the world and that the value of the commercial fish catch comes to over \$360 billion annually.

Historically, most of the global fish catch came from what are known as “capture fisheries,” which catch wild fish in the open water. However, beginning around the 1980s, global fish catch from capture fisheries began to level off even as population growth and demand for fish were increasing. Massive investments in aquaculture, or fish farming, began around that time, and today aquaculture production comes close to the same levels as that of capture fisheries. The latest statistics on production from the FAO are for 2016, when the total fish catch from capture fisheries came to 90.9 million metric tons. In that same year, fish production from aquaculture or commercial fish farming came to 80 million metric tons.

The leveling off of global fish catch from capture fisheries is *not* for lack of trying. It is simply because many commercial fisheries have been overfished for decades and are just not as productive as they once were. An estimated 4.6 million commercial fishing boats work the world’s oceans and inland waterways (FAO, 2018b). Many are equipped with high-tech GPS, sonar, and other equipment to help them locate and catch wild fish. Some commercial fishing fleets use spotter planes and drones to help them find wild fish stocks, as well as massive factory ships that process and freeze fish for months at a time out on the high seas.

The FAO defines individual fisheries as being underfished, fully fished, or overfished. *Underfished* means that fish catch from that fishery can increase and still be sustainable. *Fully fished* (or maximally sustainably fished) means that current catches are biologically sustainable but cannot be increased. And *overfished* means that current catches are biologically unsustainable and that fishery is in decline. In 1974 the FAO reported that 90% of global fisheries were either underfished or fully fished—that is, within biologically sustainable levels—and only 10% were overfished. By 2018 the percentage of global fisheries that were overfished had increased to over 33%, with another 58% being fully fished. Global production from capture fisheries has remained steady only because commercial fishing fleets are exploiting more



taylanibrahim/iStock/Getty Images Plus

**Bottom trawling, as shown in this photo, is one of the worst forms of fishing due to the damage done to the ocean floor.**

remote fishing grounds, capturing smaller fish, and targeting less desirable fish species than before.

Commercial fishing boats use a variety of techniques and equipment to catch fish, and some of these can have negative and lasting impacts on marine ecosystems. Some of the most common approaches to commercial fishing include bottom trawling, purse seining, and drift netting.

*Bottom trawling* involves dragging large, weighted fishing nets across the ocean floor. Bottom trawling is considered one of the most destructive forms of fishing and has

been compared to bulldozing the ocean floor. As the weighted nets are dragged along, they destroy deepwater reefs and other structures that are important habitat to marine life.

*Purse seining* involves the deployment of large circular nets that are drawn tighter and tighter to capture fish, while *drift nets* are long stretches of net that are laid out for miles. Both purse seining and drift netting result in the problem of **bycatch**, the accidental capture and death of nontarget species, including dolphins, sea turtles, and even seabirds. Researchers estimate that global fishing operations result in as much as 38.5 million metric tons of bycatch each year (Davies, Cripps, Nickson, & Porter, 2009).

Overfishing not only reduces commercial fishing output but also influences the composition of marine food webs. It's estimated that wild populations of large fish like tuna, marlin, and swordfish have declined by as much as 90% since the 1950s (Myers & Worm, 2003). The absence of these fish near the top of marine food chains has resulted in problems further down the chain, including large-scale jellyfish population explosions. Overfishing can affect food webs in the opposite direction as well when the capture of prey fish impacts larger fish that feed on them. Although efforts are being made to better regulate commercial fishing operations and reduce overfishing, these efforts are complicated by the fact that most of the world's ocean waters are considered "high seas" and beyond the jurisdiction of any single government.

## Habitat Destruction

We have already discussed some forms of marine and coastal habitat destruction, such as clearing of mangrove forests for fish farms, bottom trawling (bulldozing) of deepwater reefs, and demolition of shallow coral reefs through dynamite and cyanide. But there are other forms of habitat destruction as well. For example, over 60% of the world's 7.7 billion people live within 160 kilometers (100 miles) of the ocean, resulting in the heavy development of many areas along and near the coast. This has led to the destruction of many important coastal ecosystems like salt marshes, as well as increased runoff into critical coastal waters. Likewise, sediment from coastal developments, agriculture, or deforestation can wash out to sea and smother coral reef ecosystems.

Coastal and marine tourism can also cause damage. Tour boats in areas with coral reefs can damage ecosystems through dropping anchors or leaking oil. And snorkelers and divers can step on and damage fragile coral reefs, while others break pieces off for souvenirs.

## Invasive Species

Marine invasive species are organisms that have been moved from their original ocean habitat to a new one and have begun reproducing successfully. One common method by which marine invasive species are carried from one location to another is through ship ballast water. Ships store ballast water in the bottom of their hulls to make them more stable. If a ship takes in ballast water in one location and empties it in another, it can pick up invasive species and drop them somewhere else. For example, the European green crab is believed to have been introduced to North America through ballast water. This crab is a voracious feeder and in

some places has decimated local shellfish populations. European green crabs are now established on five continents and are out-competing many local species.

Another way that marine invasive species are introduced is through accidental or deliberate release into the wild. For example, lionfish are native to tropical waters in the western Pacific, but they are now a common resident off the East Coast of the United States and in the Gulf of Mexico. It's believed that lionfish got into these waters after escaping from outdoor aquariums in Florida that were damaged or destroyed by Hurricane Andrew in 1992.



*atese/iStock/Getty Images Plus*

**Lionfish are prolific breeders, consume thousands of other fish every year, and have no natural predators.**

Lionfish have been called the “vacuums of the sea” because they can consume thousands of other fish every year. Lionfish are also prolific breeders, with a single female able to spawn over 2 million eggs in one year. Because lionfish have no natural predators, and because they are protected by poisonous spines, controlling their numbers poses a challenge. Lionfish control efforts in Florida now include campaigns to get more people to capture and eat this reportedly tasty fish.

## 6.5 Sustainable Management of Ocean and Marine Ecosystems

From pollution to climate change to overfishing to habitat destruction, there are many reasons to be concerned about the future of our oceans. While these threats and challenges can seem overwhelming, there are efforts being made to slow or even reverse some of the damage we've done to ocean and marine ecosystems.

### Aquaculture

The word *aquaculture* sounds a lot like *agriculture* for a reason. **Aquaculture** is the cultivation of fish, shrimp, and other marine life in ponds, pens, cages, and other confined settings. When done right, it can help meet global demand for fish and other seafood in ways that avoid or minimize damage to marine ecosystems. However, aquaculture is not always done right, and as a result there is some controversy over just how beneficial this approach actually is.

Global aquaculture production has increased dramatically over the past 30 years, from roughly 16 million metric tons a year in 1990 to over 80 million metric tons a year today. This growth in aquaculture production occurred as capture fisheries' production was leveling off, making up the difference needed to feed a growing human population. Most aquaculture

production takes place in Asia, accounting for over 70 million of the 80 million metric tons in total world production. China alone produces 50 million metric tons of global aquaculture output (FAO, 2018b).

Because aquaculture does not require bottom trawling, purse seining, or drift netting, it avoids the kinds of problems associated with marine habitat destruction and bycatch. Raising fish in aquaculture systems also takes pressure off wild fish stocks, potentially allowing ocean fisheries to replenish.

However, a number of environmental problems have raised concerns about aquaculture's sustainability. First, farm-raised fish can escape from their ponds, pens, or cages into nearby waterways, where they pose a risk of becoming invasive species. For example, Asian carp have escaped from aquaculture facilities and are now an invasive species in the Mississippi River and threatening the Great Lakes.

Second, many of the shrimp farms in places like Thailand, the Philippines, and Vietnam have been built in coastal areas that were once covered in mangrove forests. These locations are ideal for shrimp farms because of the brackish water and flat terrain suitable for pond building, but replacing mangrove forests with shrimp farms leads to the loss of some of the critical ecosystem functions that mangroves provide, as described earlier in the chapter.



*Alexpunker/iStock/Getty Images Plus*

**An aquaculture shrimp farm in Indonesia.**

Third, just as land-based CAFOs have serious waste problems, so too do aquaculture systems. Wastewater from fish ponds is loaded with nitrogen and phosphorous that can contribute to harmful algal blooms, eutrophication, and dead zones if it is released from ponds into nearby waterways.

Fourth, because farm-raised fish tend to be packed together in small spaces, they are susceptible to disease and parasites. If not managed properly, these diseases and parasites can spread to nearby populations of wild fish.

Finally, some types of farm-raised fish (for example, Atlantic salmon) are actually fed fish meal produced from wild-caught fish species. It's estimated that as much as one fourth of all wild-caught fish is converted to fish meal for aquaculture production.

The WRI has published a number of reports that include recommendations for how to make aquaculture more sustainable (Waite, Beveridge, et al., 2014; Waite, Phillips, & Brummett, 2014). Among the most important of these recommendations are to invest in technology and innovation in the aquaculture sector and to take a landscape-level approach to locating and operating aquaculture farms. For example, the WRI recommends that fish farms be spread out to minimize the concentration of waste products and that aquaculture production adopt some of the high-tech precision approaches (satellite mapping, GPS) being increasingly adopted by land-based farmers (see Section 4.10).

In addition, the WRI recommends that more aquaculture be focused on producing varieties of fish that do not require feed made from wild fish—in other words, fish that eat low on the food chain. For example, fish like tilapia, catfish, and carp can be raised almost entirely on a vegetarian diet and therefore do not cut into wild fish stocks as carnivorous species do.

Another idea being advocated by the aquaculture industry and some environmental groups is *deepwater aquaculture*. Deepwater aquaculture involves locating large underwater cages filled with farmed fish far offshore. Deepwater aquaculture reduces the water pollution and habitat destruction problems associated with onshore fish farms because the fish are more spread out, but it still has the same risks associated with escape and disease transfer.

Regardless of the debate, large-scale aquaculture production is here to stay. The key to its ability to contribute to the sustainable management of ocean and marine ecosystems will be determined by the actual practices used in aquaculture facilities around the world.

## Ocean and Marine Policy

One of the biggest challenges with achieving sustainable management of the world's ocean and marine ecosystems is that most of the ocean is outside the jurisdiction of any one country. International law allows countries to set an exclusive economic zone (EEZ) 320 kilometers (200 miles) out from their coast and to regulate fishing and other commercial activities within their EEZ. Ocean water beyond that 320-kilometer EEZ is considered the high seas, and these areas account for 64% of the ocean's surface area and 95% of its volume. Management and regulation of fishing and other activities on the high seas is virtually nonexistent, although the United Nations Convention on the Law of the Sea (UNCLOS) is an attempt to address this. UNCLOS was adopted and signed in 1982, went into effect in 1994, and includes some provisions focused on overfishing. However, most of these provisions are limited to what each country should be doing within its own EEZ. While the United States recognizes UNCLOS as established international law, it is still not technically a part of the agreement, which was never ratified by Congress.

Within the EEZ of the United States, the Magnuson–Stevens Fishery Conservation and Management Act, often referred to as the Magnuson–Stevens Act (MSA), is the primary policy tool for regulating fisheries. The MSA sets up regional fishery management councils that develop fishery management plans for their region. Fishery management councils consider the degree to which a specific fishery is overfished and develop plans for restoration if that is the case. The management councils also set catch limits and quotas, regulate the kinds of equipment fishing fleets can use, designate certain areas as off limits to fishing, and limit trade or transport of certain types of fish.

In many poorer countries around the world, the problem of pirate fishing—or illegal, unreported, and unregulated fishing—is a serious challenge, even within their own EEZ. Pirate fishing boats are much more likely to use destructive fishing practices like bottom trawling and drift netting, and they pay no attention to catch limits, seasonal restrictions, or other regulations and policies meant to protect fish stocks and ecosystems. The World Wide Fund for Nature (n.d.) estimates that pirate fishing generates as much as \$23.5 billion in revenues each year and that an inability to enforce fishing regulations and corruption in poorer countries results in little effort to crack down on this problem.

## Marine Sanctuaries and Community Management of Fisheries

One of the primary means by which we protect wildlife and sustain ecosystems on land is through establishment of protected areas. National parks, state parks, and other forms of protected lands are a common feature in countries like the United States and make up a significant portion of the land area in many western states. However, the concept of protected areas has not transferred as easily to ocean and marine ecosystems. (The *Apply Your Knowledge* feature box explores how we might prioritize conservation efforts.)

There are two main categories of marine sanctuaries. First, **marine protected areas (MPAs)** are designed to regulate *some* human activities in marine areas for a specific conservation purpose. For example, an MPA may restrict oil and gas drilling while still allowing some forms of commercial fishing. Globally, there are over 5,000 MPAs, but these areas only make up about 3% of the world's oceans. Furthermore, MPAs still often allow some commercial and extractive activities, so they are not considered fully protected.

A second category of marine sanctuary is known as a marine reserve. **Marine reserves** are much more restrictive of human activities than MPAs, and generally they operate as “no-take zones” that completely prohibit fishing. Marine reserves are far fewer in number than MPAs, and they only account for less than 1% of the world's ocean area. In contrast, marine scientists recommend setting aside somewhere from 10% to 30% of the world's ocean area as marine reserves.

Assessments of marine biodiversity and ecosystem health in marine reserves suggest that marine reserves can be quite effective in sustaining our oceans. Once protections and restrictions on fishing are put in place, fish populations, fish size, fish reproduction, and overall biodiversity can increase dramatically in just a few years. Because fish move in and out of reserves constantly, protected areas can help increase fish populations in surrounding waters as well. The main challenge with establishing and maintaining marine reserves involves patrolling and regulating access to and use of the area. This is especially the case in some poorer countries that might lack the resources needed for effective enforcement of marine reserve rules. In some cases marine reserves, and especially MPAs, can be considered merely “paper parks,” since they lack the resources needed for effective protection of local marine ecosystems.

One way to enhance protection of marine reserves and MPAs is for governments to partner with local fishing communities. When these communities are involved in the process of planning and establishing marine reserves and can see how setting aside some fishing grounds can improve production in other nearby areas, they are often willing to get on board. Local fishers know the area and can help provide the eyes and ears needed for effective patrolling and enforcement of regulations.

Likewise, outside of marine reserves and MPAs, there is evidence that community-based management of local fishing stocks can be an effective way to sustain them. Community-based fisheries management, or *comanagement of fisheries*, is an approach that involves partnership between government agencies, scientists, and local fishing communities. Here too, the basic idea is that local fishers tend to have extensive knowledge of nearby fisheries, and when appropriate structures are in place to govern sharing and access, they can work together quite effectively to achieve sustainable management. A worldwide study of 130 fisheries where

community-based fisheries management was being practiced found that many of them were proving effective in moving toward sustainable management of local marine resources (Gutiérrez, Hilborn, & Defeo, 2011).

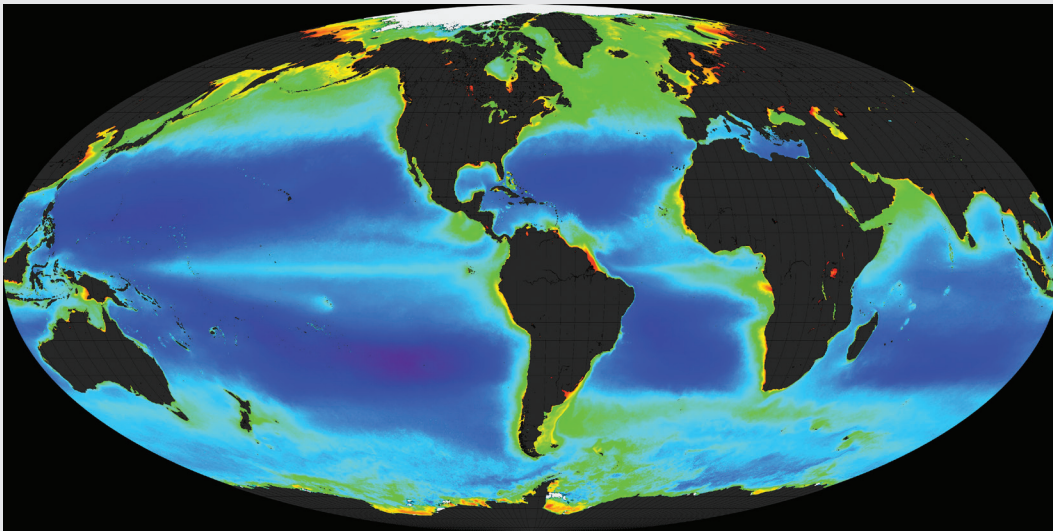
### Apply Your Knowledge: Where Is Ocean Life Most Vulnerable?

The ocean is home to a variety of ecosystems and environments. There are coral reefs, kelp forests, ocean trenches, mangroves, intertidal zones, and many other ocean habitats distributed over two thirds of the Earth's surface. With so many different environments, you might wonder which ones support the most life, which ones are most threatened by human activities, and how we should prioritize future conservation efforts.

In Figure 6.5, the world's oceans are colored to reflect the amount of photosynthesis that is occurring. To be more specific, this "primary productivity map" shows the amount of chlorophyll that is contained in organisms like kelp, algae, and plankton. These creatures are important primary producers in marine ecosystems, and wherever they are located, life is able to thrive. Using this data, see if you can determine where the most life is located and whether these locations are vulnerable to human disruptions. Most importantly, see if you can use what you have learned so far in this chapter to provide explanations for your conclusions.

#### Figure 6.5: Primary productivity maps

Where is chlorophyll most concentrated?



Source: SeaWiFs Project, n.d. (<https://earthobservatory.nasa.gov/images/4097/global-chlorophyll>).

In Figure 6.5, purple and blue regions represent locations with relatively little life, green represents areas with some life, and yellow and red locations represent areas that are densely packed with plants, animals, and microorganisms. As you might have noticed, some of the ocean's most biologically dense communities are in shallower coastal regions. Sunlight is able to reach the seafloor in these environments, where all kinds of photosynthesizing organisms like coral, kelp, and seagrass reside. These organisms are then able to support entire ecosystems by providing food and habitat.

*(continued)*

### **Apply Your Knowledge: Where Is Ocean Life Most Vulnerable?** *(continued)*

The availability of important nutrients is another reason why coastal areas are full of life. Freshwater sources carry nutrients from landmasses and deposit them along coastlines. Ocean currents bump up against continents like North America, South America, and Africa to create coastal upwelling, and this process brings nutrient-rich water from the deep ocean up to the surface. When you combine these nutrients with sunlight, you end up with coastal areas that are teeming with life.

You may have also guessed that many of these coasts are easily impacted by human activities. Because coastal waters are where many fish and shellfish reside, overfishing and aquaculture operations tend to disproportionately impact coastal ecosystems. Pollution is another important risk factor. The sediment, nutrient pollution, and plastics that you read about earlier in the chapter often enter oceans along coastlines, where they can have major environmental consequences. Finally, we have human development. Almost half of the world's population lives near a coastline, and construction, shipping, nonconsumptive water use, and even recreation can all harm sea life and destroy habitat. To make matters worse, limited freshwater resources are now leading some population centers to build desalination plants. These facilities produce freshwater by removing salts from ocean water. In the process, many facilities produce thermal pollution and salty waste materials that can damage coastal habitats.

Primary productivity maps tell an important story about the world's oceans. Sea life is concentrated along coastlines due to the availability of light and nutrients. Unfortunately, these locations are also vulnerable to harmful human activities. With this understanding, we can begin to appreciate the importance of coastal conservation and other efforts that reduce human impacts on ocean life.

## **The Consumer Role**

A final way to achieve the sustainable management of ocean and marine ecosystems is to involve individual consumers. Decisions we make about what types of seafood to purchase and eat send signals to those who catch, process, and market these products. But given all the choices out there, how are we to know whether the seafood we are purchasing was produced in a sustainable fashion?

There are at least three seafood labeling programs that are designed to take some of the mystery out of seafood purchases. By purchasing seafood products that show these labels, you are supporting fishing operations that have demonstrated that they are operating in a sustainable manner.

The first labeling program is known as the Marine Stewardship Council (MSC). The MSC is what is known as a third-party certification body in that it sets sustainability standards and assesses whether those standards are being met independent of the company or individual being assessed. MSC standards focus on three core principles:

1. maintaining sustainable fish stocks
2. minimizing environmental impact
3. promoting an effective fishery management system that respects local, national, and international laws and regulations

Fishing operations that wish to receive the MSC “certified sustainable seafood” ecolabel must undergo an audit and certification assessment to see if they meet MSC performance indicators. The MSC has been in operation since 1996, and in that time it has certified thousands of fishery operations. Despite this success, there have been complaints that the MSC does not always apply its standards consistently and that some fishery operations that are not really sustainable have still been able to achieve MSC certification (Zwerdling & Williams, 2013).

A second program, the Aquaculture Stewardship Council (ASC), uses an approach similar to that of the MSC but applied to aquaculture operations specifically. The ASC core principles focus on making sure that aquaculture operations minimize their impact on the surrounding natural environment and that they treat their workers fairly and respect local community laws and regulations. Specific ASC standards address some of the issues discussed above, like waste management, accidental escape, disease management, habitat destruction, and fish feed sourcing. Like the MSC, the ASC is an independent, third-party certifier, and as with the MSC, it awards a “farmed responsibly” ecolabel to aquaculture operations that meet its standards.

Lastly, the world-famous (thanks to the movie *Finding Dory*) Monterey Bay Aquarium has developed a Seafood Watch program to help individual consumers and businesses find seafood produced in a way that supports healthy oceans. The Seafood Watch program includes a downloadable app as well as an extensive website, each with a wealth of information on how people can make choices that support ocean and marine sustainability. While consumer-focused programs like the MSC, the ASC, and Seafood Watch cannot always have the same reach and impact as effective laws and regulations, they can contribute to improving ocean sustainability through market signals.

## Bringing It All Together

We began this chapter with the story of how salmon in the Pacific Northwest are acting as natural nutrient recyclers, carrying nitrogen and phosphorous from the deep ocean upstream to fertilize forests and ecosystems hundreds of miles from the coast. Our lives on land are connected in many ways with what happens in the oceans, no matter how far away they are or how little we know about them.

This chapter illustrates not only how the oceans affect us but also all the ways in which we affect the oceans—often with destructive impacts. We are learning more every day about the dangers our actions pose for the future of the oceans and our own well-being. To avoid the worst outcomes and to slow or even halt the degradation and destruction of ocean and marine ecosystems, we need to change the way we do a lot of things on land. For example, better farming practices and management of waste products from animal feeding operations can reduce nutrient pollution. Likewise, better solid waste management can help reduce plastic pollution in the world’s oceans. But of all these possible actions, perhaps none is

## Bringing It All Together

more important than reducing rates of ocean warming and acidification. To do that we need to make fundamental changes in the way we produce and use energy, and that issue is the focus of the next chapter.

## Additional Resources

### Our Oceans

The National Oceanic and Atmospheric Administration and the Woods Hole Oceanographic Institution are two excellent sources for all kinds of information on the oceans and ocean life.

- <https://www.noaa.gov>
- <https://www.whoi.edu>

These three TED video lectures are a good way to begin to understand just how vast and magnificent the oceans are, as well as what some of the major threats to those oceans are.

- Sylvia Earle: TED Prize Wish: Protect Our Oceans:  
<https://www.youtube.com/watch?v=pS-sfUHJaXI>
- Paul Snelgrove: A Census of the Ocean:  
<https://www.youtube.com/watch?v=PcDftBVDSLc>
- Graham Hawkes: Fly the Seas on a Submarine With Wings:  
<https://www.youtube.com/watch?v=HZCeqs-fR60>

### Ocean Currents

These two short videos provide a great explanation of ocean currents and the Coriolis effect.

- TED-Ed: How Do Ocean Currents Work?:  
<https://www.youtube.com/watch?v=p4pWafuvdrY&t=8s>
- <https://ocean.si.edu/planet-ocean/tides-currents/ocean-currents-motion-ocean>

### Plastic Pollution

There is growing evidence that plastic pollution of the oceans and waterways is reaching crisis proportions and that as plastic breaks down, it turns into microplastics that are entering the food chain and even human bodies. These links detail the extent of the problem.

- <https://www.npr.org/sections/thesalt/2019/06/06/729419975/microplastics-have-invaded-the-deep-ocean-and-the-food-chain>
- <https://www.npr.org/sections/thesalt/2018/08/20/636845604/beer-drinking-water-and-fish-tiny-plastic-is-everywhere>
- <https://marinedebris.noaa.gov>

Researchers are still learning about the implications microplastics have for human and environmental health, but these links describe some of the known and suspected risks.

- <https://blog.response.restoration.noaa.gov/plastic-pollution-and-human-health>

- <https://www.scientificamerican.com/article/from-fish-to-humans-a-microplastic-invasion-may-be-taking-a-toll>
- <https://www.ciel.org/reports/plastic-health-the-hidden-costs-of-a-plastic-planet-february-2019>

Scientists aren't the only ones trying to address the plastic pollution problem. Read about one man's efforts, and consider how you might impact your own community.

- <https://www.npr.org/sections/goatsandsoda/2019/01/15/683734379/an-island-crusader-takes-on-the-big-brands-behind-plastic-waste>

The connection between ocean currents, gyres, and ocean garbage patches can be a little difficult to understand. These sources help explain the concept and provide examples.

- <https://marinedebris.noaa.gov/info/patch.html>
- <https://oceanservice.noaa.gov/podcast/mar18/nop14-ocean-garbage-patches.html>

### Noise Pollution

These links provide additional information on the problem of ocean noise pollution.

- Kate Stafford: How Human Noise Affects Ocean Habitats:  
<https://www.youtube.com/watch?v=t-K6bn9sc50>
- [https://e360.yale.edu/features/how\\_ocean\\_noise\\_pollution\\_wreaks\\_havoc\\_on\\_marine\\_life](https://e360.yale.edu/features/how_ocean_noise_pollution_wreaks_havoc_on_marine_life)

### Ocean Acidification

Ocean acidification has been called "climate change's equally evil twin" because of the potential damage it can do to marine life and the planet. There are many resources available to better understand this somewhat complicated issue, including these.

- <https://blogs.ei.columbia.edu/2015/12/09/what-is-ocean-acidification-why-does-it-matter>
- <https://ocean.si.edu/conservation/acidification>
- <https://www.noaa.gov/education/resource-collections/ocean-coasts-education-resources/ocean-acidification>
- <https://www.iucn.org/resources/issues-briefs/ocean-acidification>

### Marine Sanctuaries

This global, interactive map of marine protected areas and TED Talk arguing for a substantial expansion of those areas are very interesting.

- <http://www.mpatlas.org/map/mpas>
- Enric Sala: Let's Turn the High Seas Into the World's Largest Nature Reserve:  
<https://www.youtube.com/watch?v=9IPHZ2rN-Hs>

## Key Terms

**aphotic zone** The region of a body of water that is beyond the reach of light from the surface.

**aquaculture** The cultivation of fish, shrimp, and other marine life in ponds, pens, cages, and other confined settings.

**atmospheric deposition** The process by which air pollutants fall to the Earth's surface.

**benthic zone** The region at the bottom or lowest level of a body of water.

**bioaccumulation** The buildup of toxins in an individual organism over time.

**bycatch** The accidental capture and death of nontarget species in fishing, including dolphins, sea turtles, and seabirds.

**coral bleaching** The whitening of corals that occurs due to the loss of zooxanthellae algae.

**Coriolis effect** The tendency for currents to move to the right in the Northern Hemisphere and to the left in the Southern Hemisphere because of the Earth's rotation.

**El Niño–Southern Oscillation (ENSO)** A recurring climate pattern that changes ocean currents and disrupts typical weather patterns.

**estuaries** Bodies of water in which freshwater from rivers mixes with salt water from the sea.

**Great Pacific Garbage Patch (GPGP)** The collective name for two garbage patches in the North Pacific Ocean that have formed as a result of plastic pollution and ocean currents.

**Gulf Stream** The major ocean current that brings warm water from the tropical regions around Florida to the northeastern United States, northeastern Canada, and northern Europe.

**gyre** A large-scale circular ocean current.

**intertidal zone** The region where a body of water meets the land.

**mangrove forests** Groupings of mangrove trees and other vegetation that grow in coastal intertidal zones.

**marine protected area (MPA)** A type of marine sanctuary designed to regulate *some* human activities in marine areas for a specific conservation purpose.

**marine reserve** A type of marine sanctuary that generally prohibits fishing and other commercial activities.

**marine snow** The slowly sinking shower of organic material in the ocean.

**microplastics** Very small pieces of plastic formed as larger pieces of plastic pollution undergo photodegradation and break apart.

**ocean acidification** The process by which the ocean becomes more acidic as a result of carbon dioxide combining with seawater to produce acid.

**ocean noise pollution** Excessive underwater environmental noise that can harm marine health.

**pelagic zone** The region of a body of water that is not associated with the shore or with the bottom. In the ocean, this is the open ocean zone.

**photic zone** The region of a body of water where light can penetrate.

**photodegradation** The process in which materials are broken down into smaller pieces by sunlight.

**phytoplankton** Microscopic marine algae.

**salt marshes** Shallow wetlands that are flooded with salt water during high tides.

**surface currents** Ocean currents that move water horizontally along the surface.

**thermohaline circulation** Vertical movement of water caused by differences in temperature and salinity.

**upwelling** An oceanic phenomenon that involves the rising of cold, nutrient-rich water.

**vertical currents** Ocean currents that move water between the surface and the depths.

