# 14

# Ocean Water and Ocean Life*

**FOCUS ON CONCEPTS**

Each statement represents the primary **LEARNING OBJECTIVE** for the corresponding major heading within the chapter. After you complete the chapter, you should be able to:

**14.1** Define *salinity* and list the main elements that contribute to the ocean's salinity. Describe the sources of dissolved substances in seawater and causes of variations in salinity.

**14.2** Discuss temperature, salinity, and density changes with depth in the open ocean.

**14.3** Distinguish among plankton, nekton, and benthos. Summarize the factors used to divide the ocean into marine life zones.

**14.4** Contrast ocean productivity in polar, midlatitude, and tropical settings.

**14.5** Define *trophic level* and discuss the efficiency of energy transfer between different trophic levels.

**Modern coral reefs are unique ecosystems of animals, plants, and their associated geologic framework. They are home to about 25 percent of all marine species. Because of this great diversity, they are sometimes referred to as the ocean equivalent of rain forests.** (Photo by Image Marine Quest)

*This chapter was prepared with the assistance of Professor Alan P. Trujillo, Palomar College.

What is the difference between pure water and seawater? One of the most obvious differences is that seawater contains dissolved substances that give it a distinctly salty taste. These dissolved substances are not simply sodium chloride (table salt); they include various other salts, metals, and even dissolved gases. In fact, every known naturally occurring element is found dissolved in at least trace amounts in seawater. Unfortunately, the salt content of seawater makes it unsuitable for drinking or for irrigating most crops and causes it to be highly corrosive to many materials. Yet, many parts of the ocean are teeming with life that is superbly adapted to the marine environment.

There is an amazing variety of life in the ocean, from microscopic bacteria and algae to the largest organism alive today (the blue whale). Water is the major component of nearly every life-form on Earth, and our own body fluid chemistry is remarkably similar to the chemistry of seawater.

## 14.1 COMPOSITION OF SEAWATER

**Define *salinity* and list the main elements that contribute to the ocean's salinity. Describe the sources of dissolved substances in seawater and causes of variations in salinity.**

Seawater consists of about 3.5 percent (by weight) dissolved mineral substances that are collectively termed "salts." Although the percentage of dissolved components may seem small, the actual quantity is huge because the ocean is so vast.

### Salinity

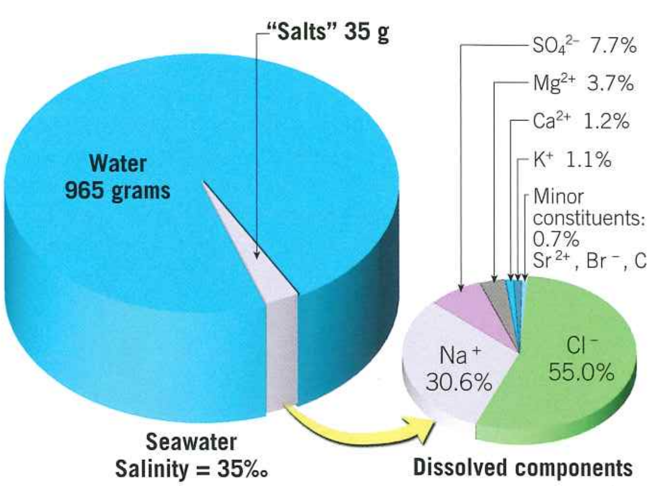
**Salinity** (*salinus* = salt) is the total amount of solid material dissolved in water. More specifically, it is the ratio of the mass of dissolved substances to the mass of the water sample. Many common quantities are expressed in percent (%), which is really *parts per hundred*. Because the proportion of dissolved substances in seawater is such a small number, oceanographers typically express salinity in *parts per thousand* (‰). Thus, the average salinity of seawater is 3.5%, or 35‰.

**FIGURE 14.1** shows the principal elements that contribute to the ocean's salinity. If one wanted to make artificial seawater, it could be approximated by following the recipe shown in **TABLE 14.1**. From this table, it is evident that most of the salt in seawater is sodium chloride—common table salt. Sodium chloride together with the next four most abundant salts comprise more than 99 percent of all dissolved substances in the sea. Although only eight elements make up these five most abundant salts, seawater contains all of Earth's other naturally occurring elements. Despite their presence in minute quantities, many of these elements are very important in maintaining the necessary chemical environment for life in the sea.

**TABLE 14.1 Recipe for Artificial Seawater**

| To Make Seawater, Combine: | Amount (grams) |
|---|---|
| Sodium chloride ($NaCl$) | 23.48 |
| Magnesium chloride ($MgCl_2$) | 4.98 |
| Sodium sulfate ($Na_2SO_4$) | 3.92 |
| Calcium chloride ($CaCl_2$) | 1.10 |
| Potassium chloride ($KCl$) | 0.66 |
| Sodium bicarbonate ($NaHCO_3$) | 0.192 |
| Potassium bromide ($KBr$) | 0.096 |
| Hydrogen borate ($H_3BO_3$) | 0.026 |
| Strontium chloride ($SrCl_2$) | 0.024 |
| Sodium fluoride ($NaF$) | 0.003 |

**Then Add:** Pure water ($H_2O$) to form 1,000 grams of solution.

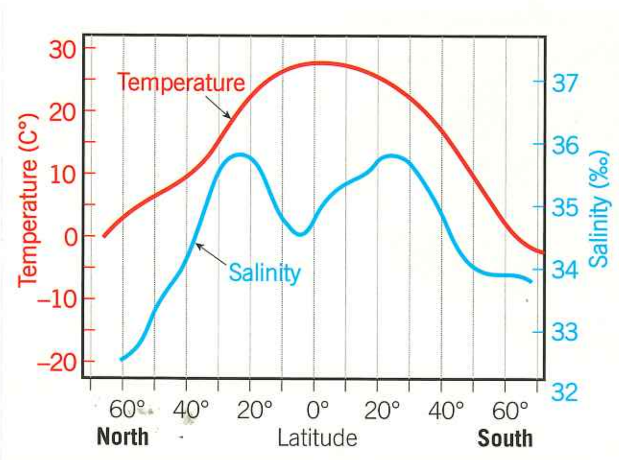



**URE 14.1 Composition eawater** The diagram ws the relative proportions ater and dissolved ponents in a typical ple of seawater.

### Sources of Sea Salts

What are the primary sources for the vast quantities of dissolved substances in the ocean? Chemical weathering of rocks on the continents is one important source. These dissolved materials are delivered to the oceans by streams at an estimated rate of more than 2.3 billion metric tons (2.5 billion short tons) annually.[1] The second major source of elements found in seawater is from Earth's interior. Through volcanic eruptions, large quantities of water vapor and other gases have been emitted during much of geologic time. This process, called *outgassing*, is the principal source of water

[1] A metric ton equals 1,000 kilograms, or 2,205 pounds. Thus, it is larger than the "ton" that most Americans are familiar with (called a *short ton*). There are 2,000 pounds in a short ton.




**SmartFigure 14.2 Variations in Surface Temperature and Salinity with Latitude** Average temperatures are highest near the equator and get colder toward the poles. Important factors influencing salinity are variations in rainfall and rates of evaporation. For example, in the dry subtropics in the vicinity of the Tropics of Cancer and Capricorn, high evaporation rates remove more water than is replaced by the meager rainfall, resulting in high surface salinities. In the wet equatorial region, abundant rainfall reduces surface salinities.

in the oceans. Certain elements—notably chlorine, bromine, sulfur, and boron—were outgassed along with water and exist in the ocean in much greater abundance than could be explained by weathering of continental rocks alone.

Although rivers and volcanic activity continually contribute dissolved substances to the oceans, the salinity of seawater is not increasing. In fact, evidence suggests that the composition of seawater has been relatively stable for millions of years. Why doesn't the sea get saltier? The answer is because material is being removed just as rapidly as it is added. For example, some dissolved components are withdrawn from seawater by organisms as they build hard parts. Other components are removed when they chemically precipitate out of the water as sediment. Still others are exchanged at the oceanic ridge by *hydrothermal* (*hydro* = water, *thermos* = hot) *activity*. The net effect is that the overall makeup of seawater has remained relatively constant through time.

## Processes Affecting Seawater Salinity

Because the ocean is well mixed, the relative abundances of the major components in seawater are essentially constant, no matter where the ocean is sampled. Variations in salinity, therefore, primarily result from changes in the water content of the solution.

Various surface processes alter the amount of water in seawater, thereby affecting salinity. Processes that add large amounts of freshwater to seawater—and thereby decrease salinity—include the addition of rain and snow, the discharge of rivers, and the melting of icebergs and sea ice. Processes that remove large amounts of freshwater from seawater—and thereby increase seawater salinity—include evaporation (in which liquid water becomes a gas and enters the atmosphere) and the formation of sea ice. High salinities, for example, are found where evaporation rates are high, as is the case in the dry subtropical regions (roughly between 25° and 35° north or south latitude). Conversely, where large amounts of precipitation dilute ocean waters, as in the midlatitudes (between 35° and 60° north or south latitude) and near the equator, lower salinities prevail. The graph in **FIGURE 14.2** shows this pattern.

Surface salinity in polar regions varies seasonally due to the formation and melting of sea ice. When seawater freezes in winter, sea salts do not become part of the ice. Therefore, the salinity of the remaining seawater increases. In summer when sea ice melts, the addition of the freshwater dilutes the solution, and salinity decreases (**FIGURE 14.3**).

The map in **FIGURE 14.4** was produced with data from the *Aquarius* satellite. It shows how ocean surface salinity varies worldwide. Notice how the overall pattern on the map matches the graph in Figure 14.2. Also notice the following:

- The Atlantic Ocean is saltiest, greater than 37‰ in some places. This is because compared to Earth's other oceans, the Atlantic has a greater inequality between the loss of freshwater via evaporation and the addition of freshwater from rainfall and river runoff.
- Notice how the huge discharge of freshwater from the Amazon River produces a zone of lower-salinity seawater in the western Atlantic off the northeast coast of South America.
- The impact of freshwater discharge from rivers is also illustrated when the salinity of the Bay of Bengal is compared to the salinity of the Arabian Sea. Freshwater from the Ganges River causes the surface salinity of the Bay of Bengal to be lower than the salinity of the Arabian Sea.

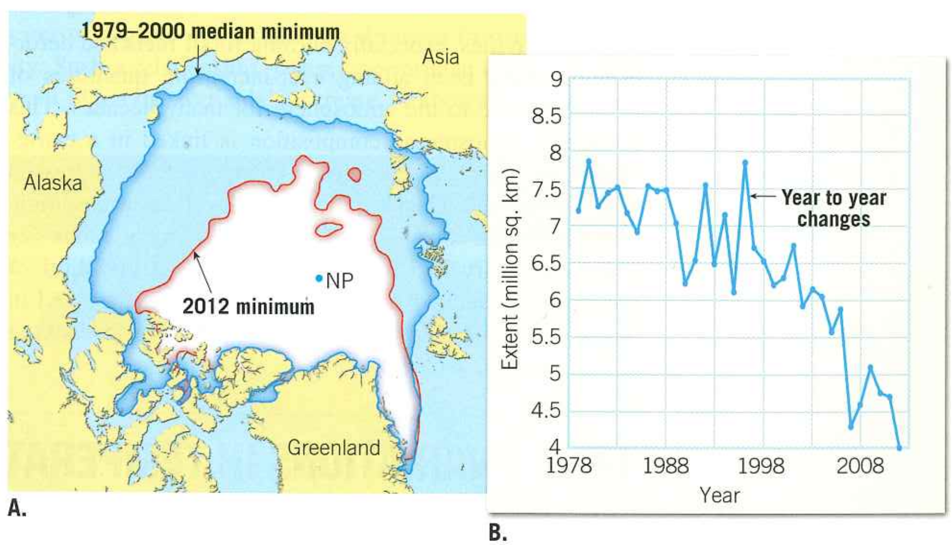



**FIGURE 14.3 Tracking Sea Ice Changes A.** Sea ice is frozen seawater. The formation and melting of sea ice influence the surface salinity of the ocean. In winter the Arctic Ocean is completely ice covered. In summer a portion of the ice melts. This map shows the extent of sea ice in early September 2012 compared to the average extent for the period 1979 to 2000. The extent in 2012 was the lowest on record. **B.** The graph clearly depicts the trend in the area covered by Arctic sea ice at the end of the summer melt period. The trend is very likely related to global climate change. (NASA)

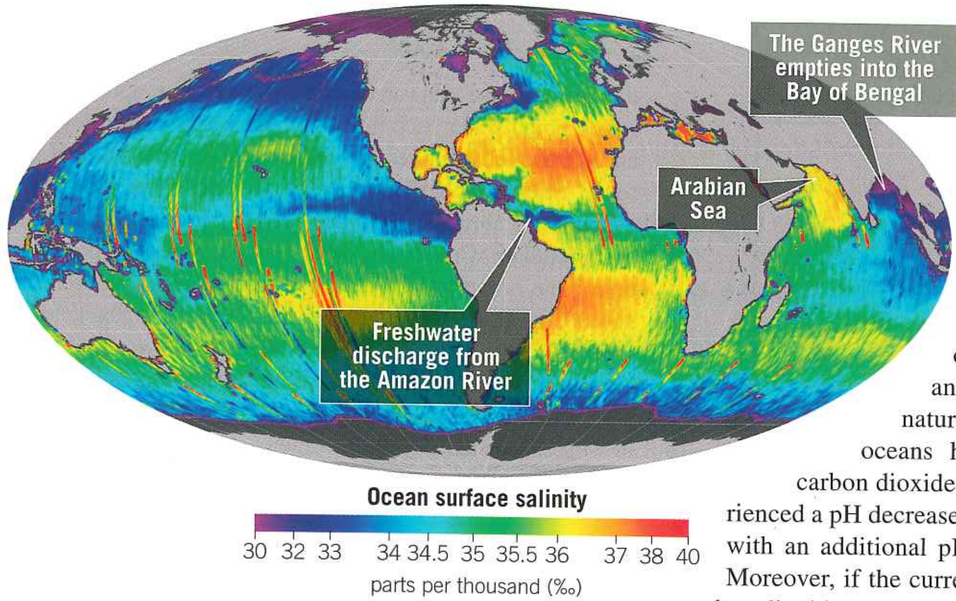



**FIGURE 14.4 Surface Salinity of the Oceans** This map shows average surface salinity for September 2012. It was created using data from the *Aquarius* satellite. (NASA)

seawater more acidic. The pH scale is shown and briefly described in **FIGURE 14.5**.

When carbon dioxide ($CO_2$) from the atmosphere dissolves in seawater ($H_2O$), it forms carbonic acid ($H_2CO_3$). This lowers the ocean's pH and changes the balance of certain chemicals found naturally in seawater. In fact, the oceans have already absorbed enough carbon dioxide for surface waters to have experienced a pH decrease of 0.1 since preindustrial times, with an additional pH decrease likely in the future. Moreover, if the current trend of human-induced carbon dioxide emissions continues, by the year 2100, the ocean will experience a pH decrease of at least 0.3, which represents a change in ocean chemistry that has not occurred for millions of years. This shift toward acidity and the changes in ocean chemistry that result make it more difficult for certain marine creatures to build hard parts out of calcium carbonate. The decline in pH thus threatens a variety of calcite-secreting organisms as diverse as microbes and corals, which concerns marine scientists because of the potential consequences for other sea life that depends on the health and availability of these organisms.

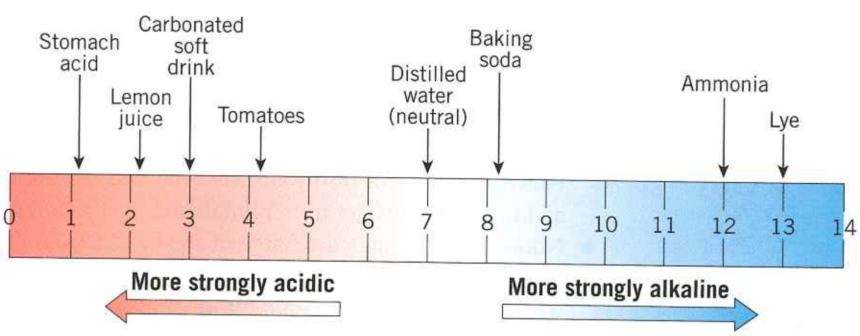



**FIGURE 14.5 The pH Scale** This is the common measure of the degree of acidity or alkalinity of a solution. The scale ranges from 0 to 14, with a value of 7 indicating a solution that is neutral. Values below 7 indicate greater acidity, whereas numbers above 7 indicate greater alkalinity. It is important to note that the pH scale is logarithmic; that is, each whole number increment indicates a tenfold difference. Thus, pH 4 is 10 times more acidic than pH 5 and 100 times (10 × 10) more acidic than pH 6.

## Recent Increase in Ocean Acidity

Human activities, especially burning fossil fuels and deforestation, have been adding ever-increasing quantities of carbon dioxide to the atmosphere for many decades. This change in atmospheric composition is linked in a cause-and-effect way to global climate change, a topic addressed at some length in Chapter 20. Rising levels of atmospheric carbon dioxide also have some serious implications for ocean chemistry and for marine life. About one-third of the human-generated carbon dioxide ends up dissolved in the oceans. This causes the ocean's pH to drop, making

### 14.1 CONCEPT CHECKS

1. What is salinity, and how is it usually expressed? What is the average salinity of the ocean?
2. What are the six most abundant elements dissolved in seawater? What is produced when the two most abundant elements combine?
3. What are the two primary sources for the elements that comprise the dissolved components in seawater?
4. List several factors that cause salinity to vary from place to place and from time to time.
5. Is the pH of the ocean increasing or decreasing? What is responsible for the changing pH?

## 14.2 VARIATIONS IN TEMPERATURE AND DENSITY WITH DEPTH

**Discuss temperature, salinity, and density changes with depth in the open ocean.**

Temperature and density are basic ocean water properties that influence such things as deep-ocean circulation and the distribution and types of life-forms. A sampling of the open ocean from the surface to the seafloor shows that these basic properties change with depth and that the changes are not the same everywhere. How and why temperature and density change with depth is the focus of this section.

## Temperature Variations

If a thermometer were lowered from the surface of the ocean into deeper water, what temperature pattern would be found? Surface waters are warmed by the Sun, so they generally have higher temperatures than deeper waters. Surface water temperatures are also higher in the tropics and get colder toward the poles.

**FIGURE 14.6** shows two graphs of temperature versus depth: one for high-latitude regions and one for low-latitude regions. The low-latitude curve begins at the surface with high temperature, but the temperature decreases rapidly with depth because of the inability of the Sun's rays to penetrate very far into the ocean. At a depth of about 1000 meters (3300 feet), the temperature remains just a few degrees above freezing and is relatively constant from this level down to the ocean floor. The layer of ocean water between about 300 meters (980 feet) and 1000 meters (3300 feet), where there is a rapid change of temperature with depth, is called the **thermocline** (*thermo* = heat, *cline* = slope). The thermocline is a very important zone in the ocean because it creates a vertical barrier to many types of marine life.

The high-latitude curve in Figure 14.6 displays a pattern quite different from the low-latitude curve. Surface-water temperatures in high latitudes are much cooler than in low latitudes, so the curve begins at the surface with low temperature. Deeper in the ocean, the temperature of the water is similar to that at the surface (just a few degrees above freezing), so the curve remains vertical, and there is no rapid change of temperature with depth. A thermocline is not present in high latitudes; instead, the water column is *isothermal* (*iso* = same, *thermal* = heat).

Some high-latitude waters can experience minor warming during the summer months. Thus, certain high-latitude regions experience an extremely weak seasonal thermocline. Midlatitude waters, on the other hand, experience a more dramatic seasonal thermocline and exhibit characteristics intermediate between high- and low-latitude regions.

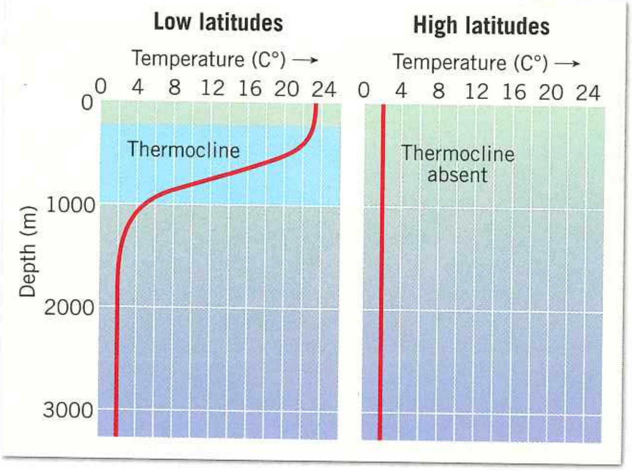



**FIGURE 14.6 Variations in Ocean Water Temperature with Depth for Low- and High-Latitude Regions** The layer of rapidly changing temperature called the *thermocline* is not present in the high latitudes.

## Density Variations

**Density** is defined as mass per unit volume but can be thought of as a measure of *how heavy something is for its size.* For instance, an object that has low density is lightweight for its size—for example, a dry sponge, foam packing, or a surfboard. Conversely, an object that has high density is heavy for its size—for example, cement and many metals.

Density is an important property of ocean water because it determines the water's vertical position in the ocean. Furthermore, density differences cause large areas of ocean water to sink or float. For example, when high-density seawater is added to low-density freshwater, the denser seawater sinks below the freshwater.

**Factors Affecting Seawater Density** Seawater density is influenced by two main factors: *salinity* and *temperature.* An increase in salinity adds dissolved substances and results in an increase in seawater density (**FIGURE 14.7**). An increase in temperature, on the other hand, causes water to expand and results in a decrease in seawater density. Such a relationship, where one variable decreases as a result of another variable's increase, is known as an *inverse*

### EYE ON EARTH

Icebergs such as this one are common in high-latitude oceans. The iceberg pictured here occurred in the Southern Ocean near Antarctica. (Photo by Steve Bloom Images/Alamy)

**QUESTION 1** *From where do icebergs originate?*

**QUESTION 2** *If melted, would the water be fresh or salty?*

**QUESTION 3** *When icebergs melt, how is surface salinity affected, if at all?*

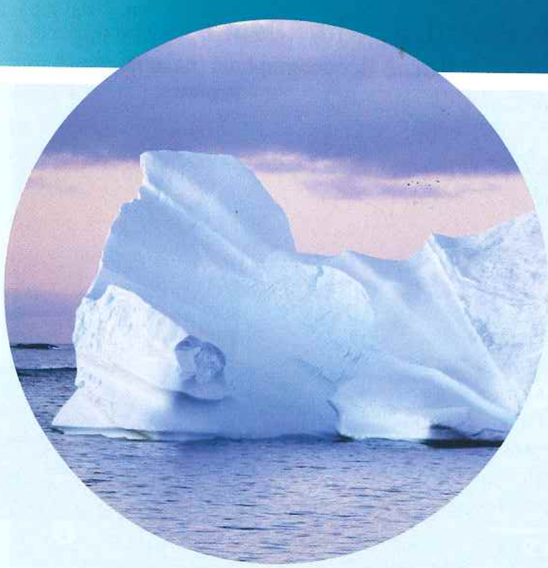
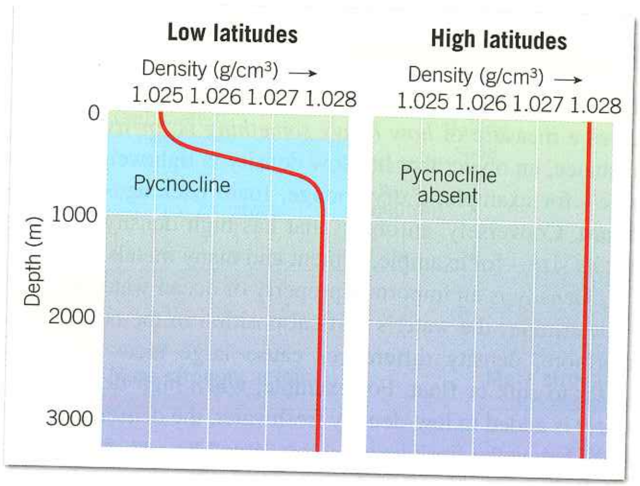


**FIGURE 14.7 The Dead Sea** This water body, which has a salinity of 330‰ (almost 10 times the average salinity of seawater), has high density. As a result, it also has high buoyancy that allows swimmers to float easily. (Photo by Peter Guttman/Corbis)

**SmartFigure 14.8 Variations in Ocean-Water Density with Depth for Low- and High-Latitude Regions** The layer of rapidly changing density called the *pycnocline* is present in the low latitudes but absent in the high latitudes.




*relationship*, where one variable is *inversely proportional* with the other.

Temperature has the greatest influence on surface seawater density because variations in surface seawater temperature are greater than salinity variations. In fact, only in the extreme polar areas of the ocean, where temperatures are low and remain relatively constant, does salinity significantly affect density. Cold water that also has high salinity is some of the highest-density water in the world.

**Density Variation with Depth** By extensively sampling ocean waters, oceanographers have learned that temperature and salinity—and the water's resulting density—vary with depth. **FIGURE 14.8** shows two graphs of density versus depth: one for high-latitude regions and one for low-latitude regions.

The low-latitude curve in Figure 14.8 begins at the surface with low density (related to high surface-water temperatures). However, density increases rapidly with depth because the water temperature is getting colder. At a depth of about 1000 meters (3300 feet), seawater density reaches a maximum value related to the water's low temperature. From this depth to the ocean floor, density remains constant and high. The layer of ocean water between about 300 meters (980 feet) and 1000 meters (3300 feet), where there is a rapid change of density with depth, is called the **pycnocline** (*pycno* = density, *cline* = slope). A pycnocline has a high gravitational stability and presents a significant barrier to mixing between low-density water above and high-density water below.

The high-latitude curve in Figure 14.8 is also related to the temperature curve for high latitudes shown in Figure 14.6. Figure 14.8 shows that in high latitudes, there is high-density (cold) water at the surface and high-density (cold) water below. Thus, the high-latitude density curve remains vertical, and there is no rapid change of density with depth. A pycnocline is not present in high latitudes; instead, the water column is *isopycnal* (*iso* = same, *pycno* = density).

## Ocean Layering

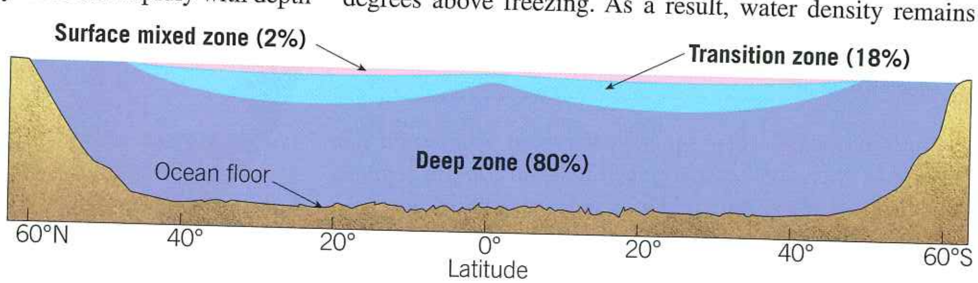
The ocean, like Earth's interior, is layered according to density. Low-density water exists near the surface, and higher-density water occurs below. Except for some shallow inland seas with a high rate of evaporation, the highest-density water is found at the greatest ocean depths. Oceanographers generally recognize a three-layered structure in most parts of the open ocean: a shallow surface mixed zone, a transition zone, and a deep zone (**FIGURE 14.9**).

Because solar energy is received at the ocean surface, it is here that water temperatures are warmest. The mixing of these waters by waves as well as turbulence from currents and tides distributes heat gained at the surface through a shallow layer. Consequently, this *surface mixed zone* has nearly uniform temperatures. The thickness and temperature of this layer vary, depending on latitude and season. The zone usually extends to about 300 meters (980 feet) but may attain a thickness of 450 meters (1500 feet). The surface mixed zone accounts for only about 2 percent of ocean water.

Below the sun-warmed zone of mixing, the temperature falls abruptly with depth (see Figure 14.6). Here, a distinct layer called the *transition zone* exists between the warm surface layer above and the deep zone of cold water below. The transition zone includes a prominent thermocline and associated pycnocline and accounts for about 18 percent of ocean water.

Below the transition zone is the *deep zone*, where sunlight never reaches and water temperatures are just a few degrees above freezing. As a result, water density remains

**IGURE 14.9 The Ocean's Layers** Oceanographers ecognize three main layers in the ocean, based on water ensity, which varies with temperature and salinity. The warm *urface mixed layer* accounts for only 2 percent of ocean water; he *transition zone* includes the thermocline and the pycnocline nd accounts for 18 percent of ocean water; and the *deep zone* ontains cold, high-density water that accounts for 80 percent of cean water.



constant and high. Remarkably, the deep zone includes about 80 percent of ocean water, indicating the immense depth of the ocean. (The average depth of the ocean is more than 3700 meters [12,200 feet].)

In high latitudes, the three-layer structure does not exist because the water column is isothermal and isopycnal, which means there is no rapid change in temperature or density with depth. Consequently, good vertical mixing between surface and deep waters can occur in high-latitude regions. Here, cold, high-density water forms at the surface, sinks, and initiates deep-ocean currents, which are discussed in Chapter 15.

## 14.2 CONCEPT CHECKS

1. Contrast temperature variations with depth in the high and low latitudes. Why do high-latitude waters generally lack a thermocline?
2. What two factors influence seawater density? Which one has the greater influence on surface seawater density?
3. Contrast density variations with depth in the high and low latitudes. Why do high-latitude waters generally lack a pycnocline?
4. Describe the ocean's layered structure. Why does the three-layer structure not exist in high latitudes?

# 14.3 THE DIVERSITY OF OCEAN LIFE

**Distinguish among plankton, nekton, and benthos. Summarize the factors used to divide the ocean into marine life zones.**

A wide variety of organisms inhabit the marine environment. These organisms range in size from microscopic bacteria and algae to blue whales, which are as long as three buses lined up end to end. Marine biologists have identified more than 250,000 marine species, a number that is constantly increasing as new organisms are discovered and classified.

Most marine organisms live within the sunlit surface waters of the ocean. Strong sunlight supports **photosynthesis** (*photo* = light, *syn* = with, *thesis* = an arranging) by marine algae, which either directly or indirectly provide food for the vast majority of marine organisms. All marine algae live near the surface because they need sunlight; most marine animals also live near the surface because this is where food can be obtained. In shallow-water areas close to land, sunlight reaches all the way to the bottom, resulting in an abundance of marine life on the ocean floor.

There are advantages and disadvantages to living in the marine environment. One advantage is that there is an abundance of water available, which is necessary for supporting all types of life. One disadvantage is that maneuvering in water, which has high density and impedes movement, can be difficult. The success of marine organisms depends on their ability to avoid predators, find food, and cope with the physical challenges of their environment.

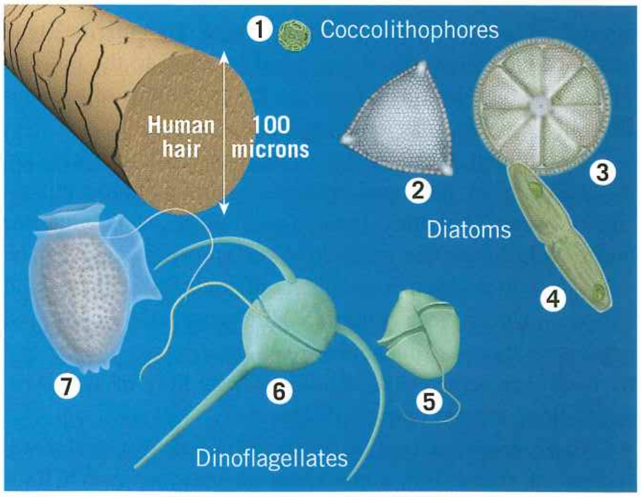
## Classification of Marine Organisms

Marine organisms can be classified according to where they live (their habitat) and how they move (their mobility). Organisms that inhabit the water column can be classified as either *plankton* (floaters) or *nekton* (swimmers). All other organisms are *benthos* (bottom dwellers).

**Plankton (Floaters)** All organisms—algae, animals, and bacteria—that drift with ocean currents are **plankton** (*planktos* = wandering). Just because plankton drift does not mean they are unable to swim. Many plankton can swim but either move very weakly or move only vertically within the water column.

Among plankton, the algae (photosynthetic cells, most of which are microscopic) are called **phytoplankton**, and the animals are called **zooplankton** (*zoo* = animal, *planktos* = wandering). Representative members of each group are shown in **FIGURE 14.10**.

**Phytoplankton:**
**(1) Coccolithophores; (2–4) Diatoms; (5–7) Dinoflagellates.**




**Zooplankton:**
**(1) Squid larva; (2) Copeod; (3) Snail larva; (4) Fish larva; (5) Arrowworm; (6) Foraminifers; (7) Radiolarian.**

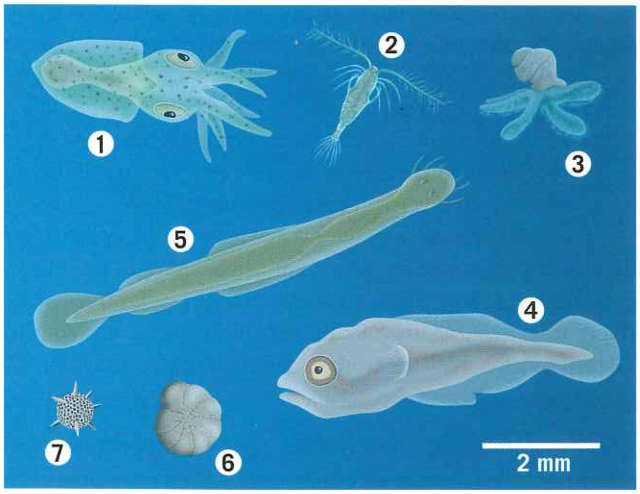
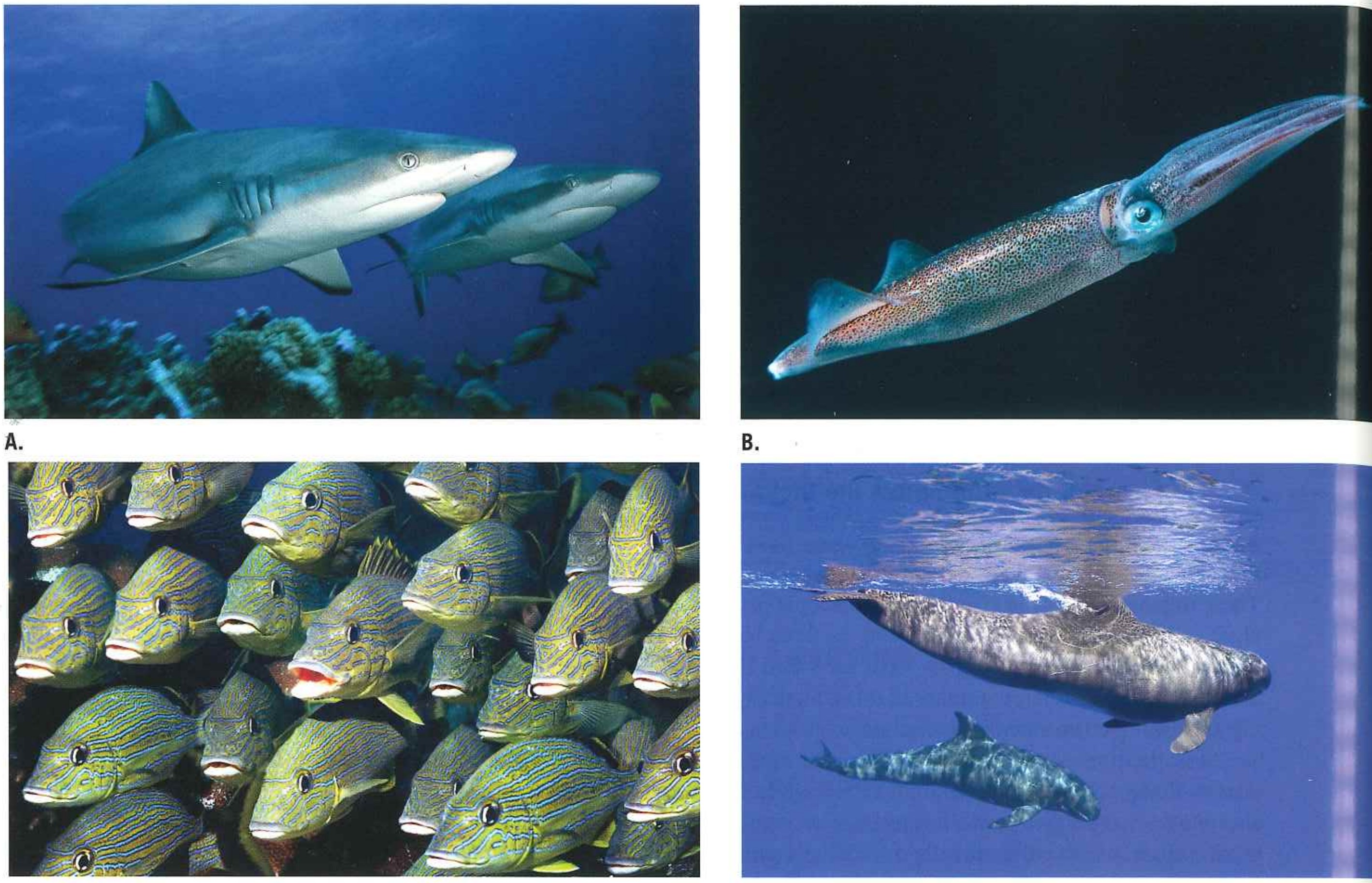



**FIGURE 14.10 Phytoplankton and Zooplankton (Floaters)** Schematic drawings of various phytoplankton and zooplankton. (After TRUJILLO, ALAN P.; THURMAN, HAROLD V., ESSENTIALS OF OCEANOGRAPHY, 11th Ed., ©2014, p.364. Reprinted and Electronically reproduced by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.)



A. B. C. D.

**URE 14.11 Nekton** All nals capable of moving pendently of ocean ents are nekton. **A.** reef shark, Bikini Atoll. o by Yann Hubert/Science ce); **B.** California market d. (Photo by Tom McHugh/ ce Source); **C.** School of ts, Florida Keys. (Photo by gie Holland/AGE fotostock); ygmy Killer Whales in low surface waters along Kona Coast, Big Island, aii. (Photo by Image Marine t)

Plankton are extremely abundant and very important within the marine environment. In fact, most of Earth's **biomass**—the mass of all living organisms—consists of plankton adrift in the oceans. Even though 98 percent of marine species are bottom dwelling, the vast majority of the ocean's biomass is planktonic.

**Nekton (Swimmers)** All animals capable of moving independently of ocean currents, by swimming or other means of propulsion, are called **nekton** (*nektos* = swimming). They are capable not only of determining their position within the ocean but also, in many cases, of long migrations. Nekton include most adult fish and squid, marine mammals, and marine reptiles (**FIGURE 14.11**).

Although nekton move freely, they are unable to move throughout the breadth of the ocean. Gradual changes in temperature, salinity, density, and availability of nutrients effectively limit their lateral range. The deaths of large numbers of fish, for example, can be caused by temporary shifts of water masses in the ocean. High water pressure at depth normally limits the vertical range of nekton.

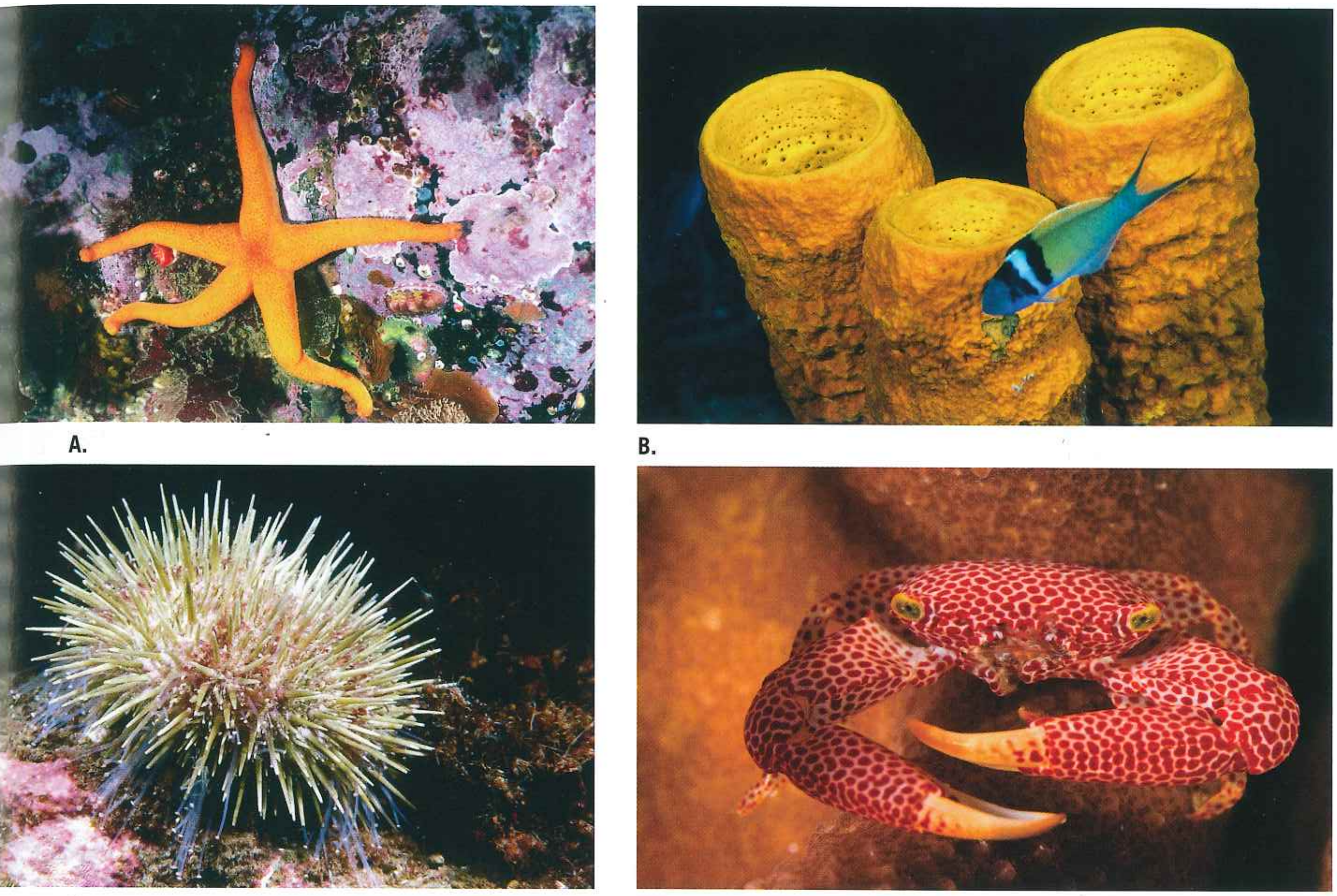
Fish may appear to exist everywhere in the oceans, but they are most abundant near continents and islands and in colder waters. Some fish, such as salmon, ascend freshwater rivers to spawn. Many eels do just the reverse, growing to maturity in freshwater and then descending streams to breed in the great depths of the ocean.

**Benthos (Bottom Dwellers)** The term **benthos** (*benthos* = bottom) describes organisms living on or in the ocean bottom. *Epifauna* (*epi* = upon, *fauna* = animal) live on the surface of the seafloor, either attached to rocks or moving along the bottom. *Infauna* (*in* = inside, *fauna* = animal) live buried in the sand or mud. Some benthos, called *nektobenthos*, live on the bottom but also swim or crawl through the water above the ocean floor. Examples of benthos are shown in **FIGURE 14.12**.

The shallow coastal ocean floor contains a wide variety of physical conditions and nutrient levels, both of which have allowed a great number of species to evolve. Moving across the bottom from the shore into deeper water, the number of benthos species may remain relatively constant, but the biomass of benthos organisms decreases. In addition, shallow coastal areas are the only locations where large marine algae (often called "seaweeds") are found attached to the bottom. This is the case because these are the only areas of the seafloor that receive sufficient sunlight.

Throughout most of the deeper parts of the seafloor, animals live in perpetual darkness, where photosynthesis cannot occur. They must feed on each other, or on whatever nutrients fall from the productive surface waters above. The deep-sea bottom is an environment of coldness, stillness, and darkness. Under these conditions, life progresses slowly, and organisms that live in the deep sea usually are widely distributed because physical conditions vary little on the deep-ocean floor, even over great distances.

There is one exception to the situation just described. Instead of sparse life, some spots on the deep-ocean floor



A. B. C. D.

**SmartFigure 14.12 Benthos** Organisms living on or in the ocean bottom are classified as benthos. **A.** Sea star. (Photo by David Hall/Science Source); **B.** Yellow tube sponge. (Photo by Andrew J. Martinez/Science Source); **C.** Green sea urchin. (Photo by Andrew J. Martinez/Science Source); **D.** Coral crab. (Photo by Images & Stories/Alamy)

exhibit abundant life-forms. These places, called *hydrothermal vents*, are found along portions of the oceanic ridge system. There is more about these unique features in the GEOgraphics "Deep-Sea Hydrothermal Vents," on page 442.

## Marine Life Zones

The distribution of marine organisms is affected by the chemistry, physics, and geology of the oceans. Marine organisms are influenced by a variety of physical oceanographic factors. Some of these factors—such as availability of sunlight, distance from shore, and water depth—are used to divide the ocean into distinct marine life zones (**TABLE 14.2** and **FIGURE 14.13**).

### Availability of Sunlight

The upper part of the ocean into which sunlight penetrates is called the **photic** (*photos* = light) **zone**. The clarity of seawater is affected by many factors, such as the amount of plankton, suspended sediment, and decaying organic particles in the water. In addition, the amount of sunlight varies with atmospheric conditions, time of day, season of the year, and latitude.

The **euphotic** (*eu* = good, *photos* = light) **zone** is the portion of the photic zone near the surface where light is strong enough for photosynthesis to occur. In the open ocean, this zone can reach a depth of 100 meters (330 feet), but the zone is much shallower close to shore, where water clarity is typically reduced. In the euphotic zone, phytoplankton use sunlight to produce food molecules and become the basis of most oceanic food webs.

Different wavelengths of sunlight are absorbed as they pass through seawater. The longer-wavelength red and orange colors are absorbed first, the greens and yellows next, and the shorter-wavelength blues and violets penetrate the farthest. In fact, faint traces of blue and violet light can still be measured in extremely clear water at depths of 1,000 meters (3,300 feet).

Although photosynthesis cannot occur much below 100 meters (330 feet), there is enough light in the lower photic zone for marine animals to avoid predators, find food, recognize their species, and locate mates. Even deeper is the **aphotic** (*a* = without, *photos* = light) **zone**, where there is no sunlight.

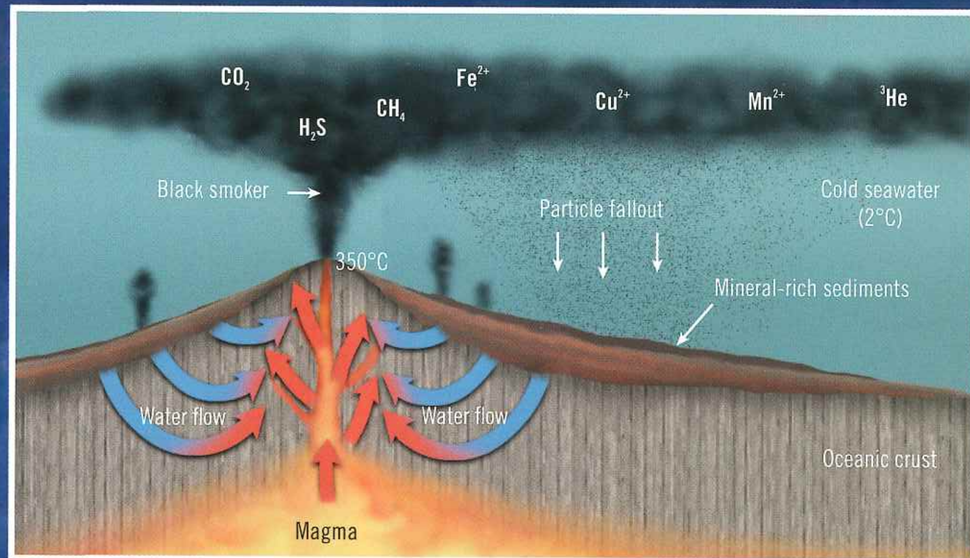
**TABLE 14.2 Marine Life Zones**

| Basis | Marine Life Zone | Subdivision | Characteristics |
|---|---|---|---|
| Available sunlight | Photic | | Sunlit surface waters |
| | | Euphotic | Has enough sunlight to support photosynthesis |
| | Aphotic | | No sunlight; many organisms have bioluminescent capabilities |
| Distance from shore | Intertidal | | Narrow strip of land between high and low tides; dynamic area |
| | Neritic | | Above continental shelf; high biomass and diversity of species |
| | Oceanic | | Open ocean beyond the continental shelf; low nutrient concentrations |
| Depth | Pelagic | | All water above the ocean floor; organisms swim or float |
| | Benthic | | Bottom of ocean; organisms attach to, burrow into, or crawl on seafloor |
| | | Abyssal | Deep-sea bottom; dark, cold, high pressure; sparse life |

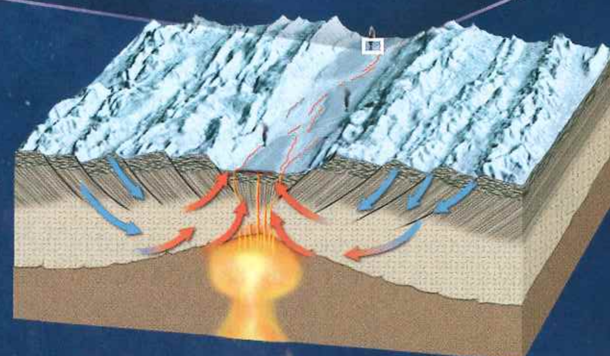
# Deep-Sea Hydrothermal Vents

**Deep-sea hydrothermal vents are openings in the oceanic crust from which geothermally heated water rises. They are found mainly along the oceanic ridge system where tectonic plates rift apart, resulting in the production of new seafloor by upwelling magma.**

When these hot, mineral-rich fluids reach the seafloor their temperatures can exceed 350 °C, but because of the extremely high pressures exerted by the water column above, they do not boil. When this hydrothermal fluid comes into contact with the much colder chemical-rich seawater, mineral matter rapidly precipitates to form shimmering smoke-like clouds called *"black smokers."* The particles that compose the black smokers eventually settle out of the seawater. These deposits may contain economically significant amounts of iron, copper, zinc, lead, and occasionally silver and gold.

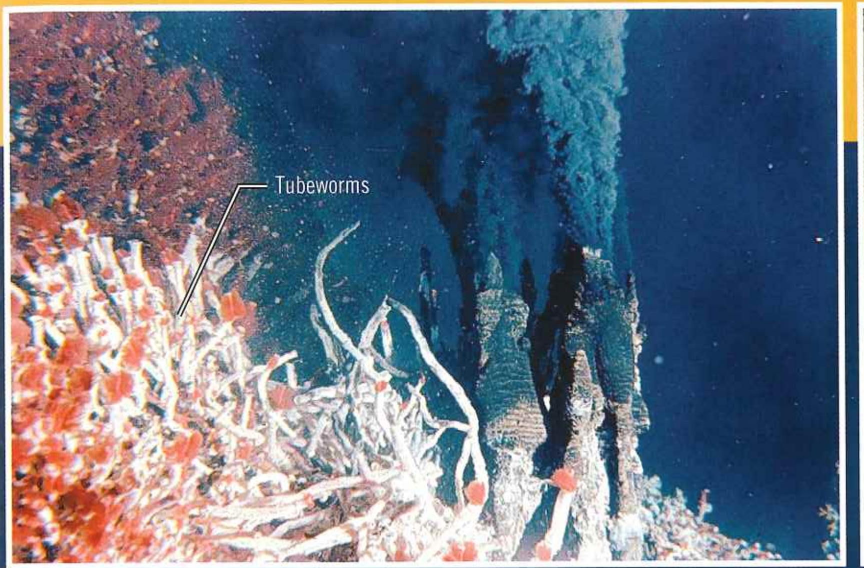



At oceanic ridges, cold seawater circulates hundreds of meters down into the highly fractured basaltic crust, where it is heated by magmatic sources. Along the way, the hot water strips metals and other elements such as sulfur from surrounding rock. This heated fluid eventually becomes hot and buoyant enough to rise along conduits and fractures towards the surface.



Some minerals immediately solidify and contribute to the formation of spectacular chimney-like structures, which can be as tall as 15-story buildings, and are appropriately given names like *Godzilla* and *Inferno.*

NOAA




Fisheries and Oceans Canada
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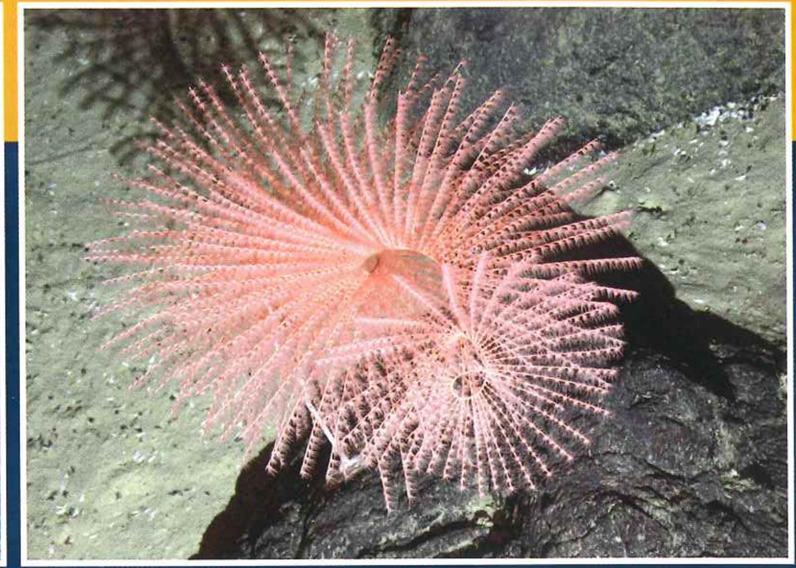
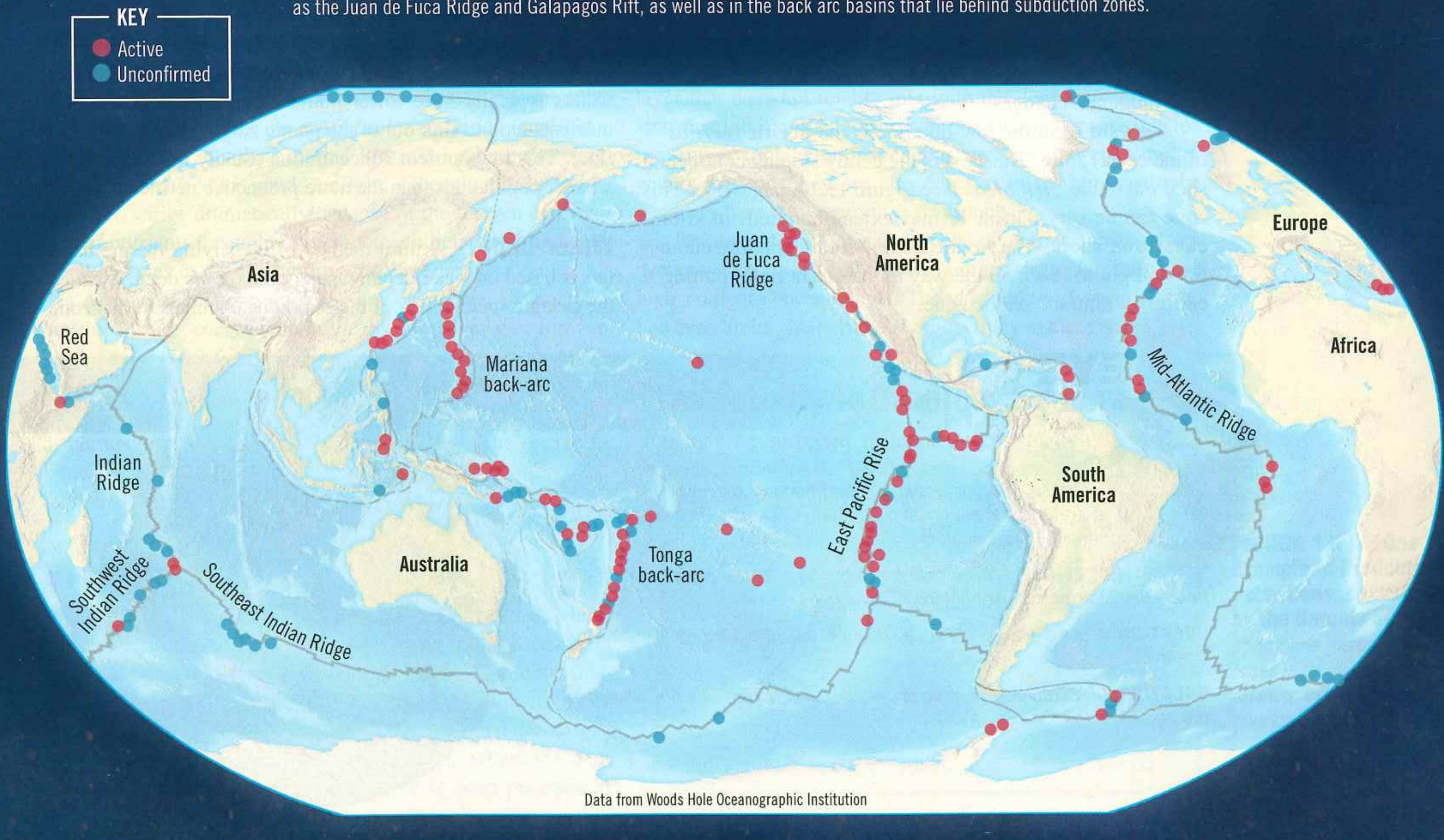


B. Murton/Southhampton Oceanography Center/
Science Source

Hydrothermal vents are also remarkable for the marine biology they support. In these environments, completely devoid of sunlight, microorganisms utilize mineral-rich hydrothermal fluid to perform chemosynthesis—the conversion of carbon atoms into organic compounds without sunlight for energy. The microbial communities, in turn, support larger, more complex animals such as fish, crabs, worms, mussels, clams, and perhaps the most unique, the tubeworm. With their white chitinous tubes and bright red plumes, these conspicuous creatures rely entirely on bacteria growing in their trophosome, an internal organ designed for harvesting bacteria. These symbiotic bacteria rely on the tubeworm to provide them with a suitable habitat and, in return, they use chemosynthesis to provide carbon-based building blocks (nutrients) to the tubeworms.

## Where are hydrothermal vents found?

Most hydrothermal vents are found around the oceanic ridge system including some small spreading centers such as the Juan de Fuca Ridge and Galapagos Rift, as well as in the back arc basins that lie behind subduction zones.




Data from Woods Hole Oceanographic Institution

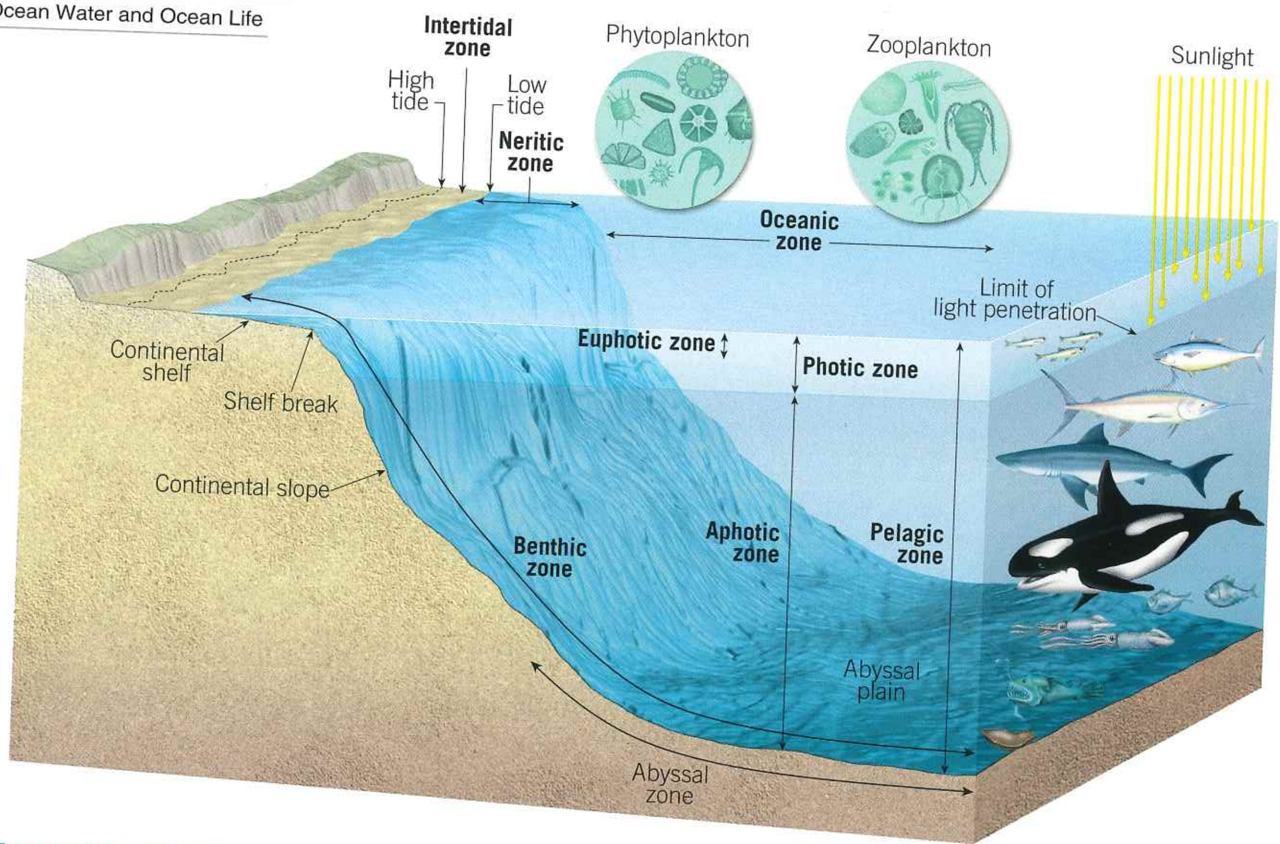



**FIGURE 14.13 Marine Life Zones** Criteria for determining life zones include availability of light, distance from shore, and water depth.

**Distance from Shore** Marine life zones are also subdivided based on distance from shore. The area where the land and ocean meet and overlap is called the **intertidal zone**. This narrow strip of land between high and low tides is alternately covered and uncovered by seawater with each tidal change. Even though it appears to be a harsh place to live with crashing waves, periodic drying out, and rapid changes in temperature, salinity, and oxygen concentrations, many species live here that are superbly adapted to the dramatic environmental changes.

Seaward from the low-tide line is the **neritic** (*neritos* = of the coast) **zone**. This covers the gently sloping continental shelf out to the *shelf break* (see Figure 13.10, page 417). This zone can be very narrow or may extend hundreds of kilometers from shore. The neritic zone is often shallow enough for sunlight to reach all the way to the ocean floor, putting it entirely within the photic zone.

Although the neritic zone covers only about 5 percent of the world's oceans, it is rich in both biomass and number of species. Many organisms find the conditions here ideal because photosynthesis occurs readily, nutrients wash in from the land, and the bottom provides shelter and habitat. This zone is so rich, in fact, that it supports 90 percent of the world's commercial fisheries.

Beyond the continental shelf is the **oceanic zone**. The open ocean reaches great depths, and as a result, surface waters typically have lower nutrient concentrations because nutrients tend to sink out of the photic zone to the deep-ocean floor. This low nutrient concentration usually results in much smaller populations than the more productive neritic zone.

**Water Depth** A third method of classifying marine habitats is based on water depth. Open ocean of *any* depth is called the **pelagic** (*pelagios* = of the sea) **zone**. Animals in this zone

## EYE ON EARTH

These dolphins were photographed in the relatively shallow waters near the coast of southern California. (Photo by Danny Frank/AGE Fotostock)

**QUESTION 1** *Which of these terms best fits the organisms shown here—plankton, nekton, or benthos? Explain.*

**QUESTION 2** *Is the marine life zone shown in this photo intertidal, neritic, or oceanic?*

**QUESTION 3** *Which term, benthic or pelagic, best fits the situation shown in the photo?*

swim or float freely. The photic part of the pelagic zone is home to phytoplankton, zooplankton, and nekton, such as tuna, sea turtles, and dolphins. The aphotic part has strange species like viperfish and giant squid that are adapted to life in deep water.

Benthos organisms such as giant kelp, sponges, crabs, sea anemones, sea stars, and marine worms that attach to, crawl upon, or burrow into the seafloor occupy parts of the **benthic** (*benthos* = bottom) **zone**. The benthic zone includes any sea-bottom surface, regardless of its distance from shore, and is mostly inhabited by benthos organisms.

The **abyssal** (*a* = without, *byssus* = bottom) **zone** is a subdivision of the benthic zone and includes the deep-ocean floor, such as *abyssal plains*. This zone is characterized by extremely high water pressure, consistently low temperature, no sunlight, and sparse life. Three food sources exist at abyssal depths: (1) tiny decaying particles steadily "raining" down from above, which provide food for filter-feeders, brittle stars, and burrowing worms; (2) large fragments or entire dead bodies falling at scattered sites, which supply meals for actively searching fish, such as the grenadier, tripodfish, and hagfish, which locate food by chemical sensing; and (3) the hydrothermal vents described in the GEOgraphics.

## 14.3 CONCEPT CHECKS

1. Describe the lifestyles of plankton, nekton, and benthos, and give examples of each. Which group comprises the largest biomass?
2. List three physical factors that are used to divide the ocean into marine life zones. How does each factor influence the abundance and distribution of marine life?
3. Why are there greater numbers and types of organisms in the neritic zone than in the oceanic zone?

# 14.4 OCEAN PRODUCTIVITY

**Contrast ocean productivity in polar, midlatitude, and tropical settings.**

Why are some regions of the ocean teeming with life, while other areas seem barren? The answer is related to the amount of primary productivity in various parts of the ocean. **Primary productivity** is the amount of carbon fixed by organisms through the synthesis of organic matter using energy derived from solar radiation (*photosynthesis*) or chemical reactions (*chemosynthesis*). Although chemosynthesis supports hydrothermal vent biocommunities along the oceanic ridge, it is much less significant than photosynthesis in worldwide oceanic productivity.

Two factors influence a region's photosynthetic productivity: *availability of nutrients* (such as nitrates, phosphorus, iron, and silica) and the *amount of solar radiation* (sunlight). Thus, the most abundant marine life exists where there are ample nutrients and good sunlight. Oceanic productivity, however, varies dramatically because of the uneven distribution of nutrients throughout the photosynthetic zone and seasonal changes in the availability of solar energy.

A permanent *thermocline* (and resulting *pycnocline*) develops nearly everywhere in the oceans. This layer forms a barrier to vertical mixing and prevents the resupply of nutrients to sunlit surface waters. In the midlatitudes, a thermocline develops only during the summer season, and in polar regions a thermocline does not usually develop at all. The degree to which waters develop a thermocline profoundly affects the amount of productivity observed at different latitudes.

## Productivity in Polar Oceans

Polar regions such as the Arctic Ocean's Barents Sea, which is off the northern coast of Europe, experience continuous darkness for about 3 months of winter and continuous illumination for about 3 months during summer. Productivity of phytoplankton—mostly single-celled algae called *diatoms*—peaks there during May (**FIGURE 14.14**), when the Sun rises high enough in the sky that there is deep penetration of sunlight into the water. As soon as the diatoms develop, zooplankton—mostly small crustaceans called *copepods* and larger *krill*—begin feeding on them. The zooplankton biomass peaks in June and continues at a relatively high level until winter darkness begins in October.

Recall that temperature and density change very little with depth in polar regions (see Figures 14.6 and 14.8), so these waters are *isothermal*, and there is no barrier to mixing between surface waters and deeper, nutrient-rich waters. In the summer, however, melting ice creates a thin, low-salinity layer that does not readily mix with the deeper waters. This stratification is crucial to summer production because it helps prevent phytoplankton from being carried into deeper, darker waters. Instead, they are concentrated in the sunlit surface waters, where they reproduce continuously.

Because of the constant supply of nutrients rising from deeper waters below, high-latitude surface waters typically have high nutrient concentrations. The availability of solar energy, however, limits photosynthetic productivity in these areas.

## Productivity in Tropical Oceans

You may be surprised to learn that productivity is low in tropical regions of the open ocean. Because the Sun is more directly overhead, light penetrates much deeper into tropical

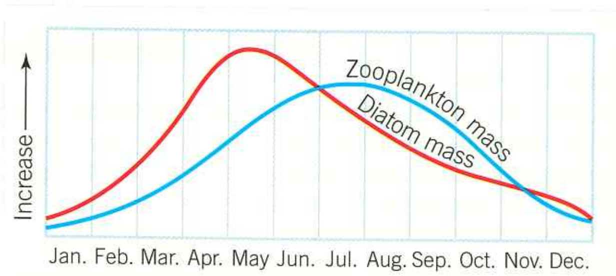



**FIGURE 14.14 One Example of Productivity in Polar Oceans Illustrated by the Barents Sea** A springtime increase in diatom mass is followed closely by an increase in zooplankton abundance.

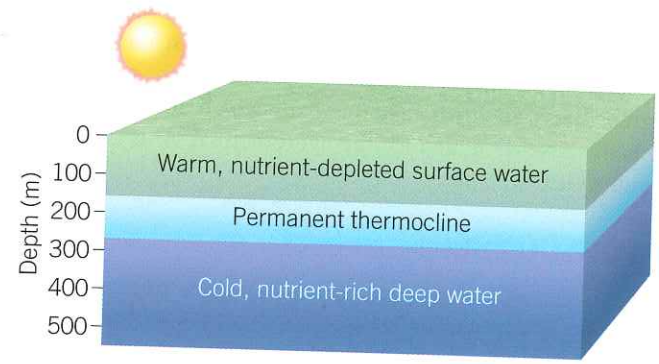



**FIGURE 14.15 Productivity in Tropical Oceans** Although tropical regions receive adequate sunlight year-round, a permanent thermocline prevents the mixing of surface and deep water. As phytoplankton consume nutrients in the surface layer, productivity is limited because the thermocline prevents replenishment of nutrients from deeper water. Thus, productivity remains at a steady, low level.

oceans than in temperate and polar waters, and solar energy is available year-round. However, productivity is low in tropical regions of the open ocean because a permanent thermocline produces a stratification of water masses that prevents mixing between surface waters and nutrient-rich deeper waters (**FIGURE 14.15**). In essence, the thermocline is a barrier that eliminates the supply of nutrients from deeper waters below. So, productivity in tropical regions is limited by the lack of nutrients (unlike in polar regions, where productivity is limited by the lack of sunlight). In fact, these areas have so few organisms that they are considered biological deserts.

## Productivity in Midlatitude Oceans

Productivity is limited by available sunlight in polar regions and by nutrient supply in the tropics. In midlatitude regions, a combination of these two limiting factors controls productivity, as shown in **FIGURE 14.16** (which shows the pattern for the Northern Hemisphere; in the Southern Hemisphere, the seasons are reversed).

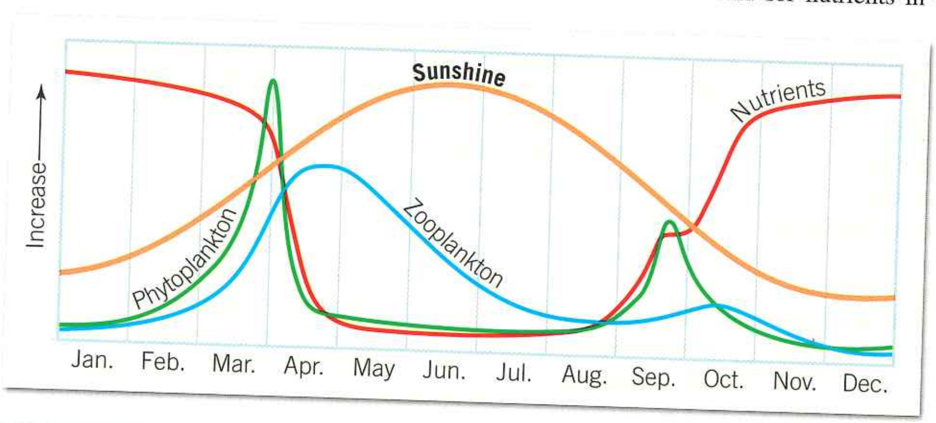
**Winter** Productivity is very low during winter, even though nutrient concentrations are highest at this time. The reason is that solar energy is limited because the length of daylight is short and the Sun angle is low. As a result, the depth at which photosynthesis can occur is so shallow that phytoplankton do not grow much.

**Spring** The Sun rises higher in the sky during spring, creating a greater depth at which photosynthesis can occur. A *spring bloom* of phytoplankton occurs because solar energy and nutrients are available, and a seasonal thermocline develops (due to increased solar heating) that traps algae in the euphotic zone (**FIGURE 14.17**). This creates a tremendous demand for nutrients in the euphotic zone, so the supply is quickly depleted, causing productivity to decrease sharply. Even though the days are lengthening and sunlight is increasing, productivity during the spring bloom is limited by the lack of nutrients.

**Summer** The Sun rises even higher in the summer, so surface waters continue to warm. A strong thermocline develops that prevents vertical mixing, so nutrients depleted from surface waters cannot be replaced by those from deeper waters. Throughout summer, the phytoplankton population remains relatively low (see Figure 14.16).

**Fall** Solar radiation diminishes in the fall as the Sun moves lower in the sky, so surface temperatures drop, and the summer thermocline breaks down. Nutrients return to the surface layer as increased wind strength mixes surface waters with deeper waters. These conditions create a *fall bloom* of phytoplankton, which is much less dramatic than the spring bloom (see Figure 14.16). The fall bloom is very short-lived because sunlight (not nutrient

**SmartFigure 14.16 Productivity in Temperate Oceans (Northern Hemisphere)** The graph shows the relationship among phytoplankton, zooplankton, amount of sunshine, and nutrient levels for surface waters.



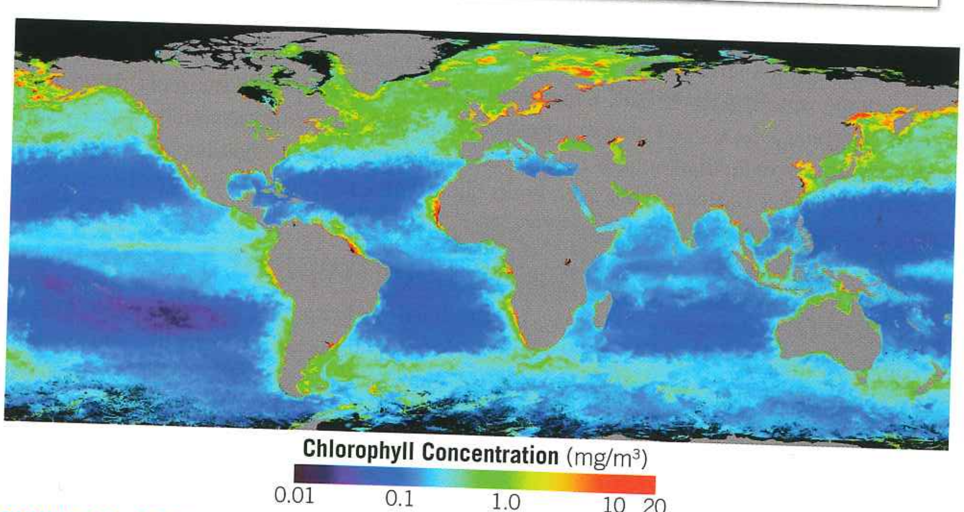




**FIGURE 14.17 Chlorophyll Concentrations Measured by Satellite Instruments** Bright greens, yellows, and reds indicate that the northern oceans were alive with plant life in the spring of 2006. High chlorophyll concentrations indicate high amounts of photosynthesis. Observations of global chlorophyll patterns tell scientists where ocean surface plants (phytoplankton) are growing, which is an indicator of where marine ecosystems are thriving. Such global maps also give scientists an idea of how much carbon the plants are soaking up, which is important in understanding the global carbon budget. (NASA)

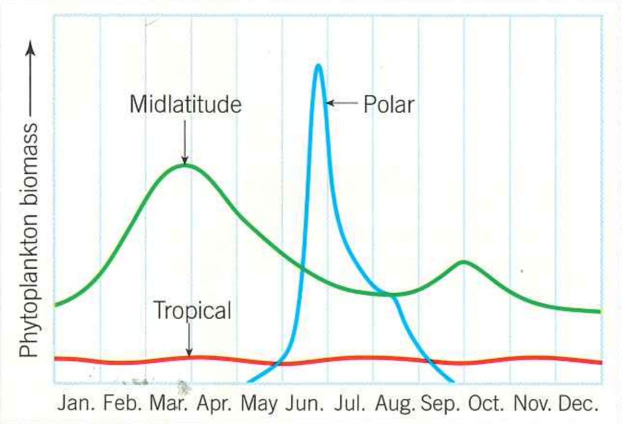



**FIGURE 14.18 Comparing Productivity** This comparison of tropical, midlatitude, and polar oceans in the Northern Hemisphere shows seasonal variations in phytoplankton biomass. The total area under each curve represents annual photosynthetic productivity.

supply, as in the spring bloom) becomes the limiting factor as winter approaches to repeat the seasonal cycle.

**FIGURE 14.18** compares the seasonal variation in phytoplankton biomass of tropical, polar, and midlatitude regions. The total area under each curve represents photosynthetic productivity. The graph shows the dramatic peak in productivity in polar oceans during the summer; the steady, low rate of productivity year-round in the tropical oceans; and the seasonal productivity that occurs in midlatitude oceans. It also shows that the highest overall productivity occurs in the midlatitudes.

## 14.4 CONCEPT CHECKS

1 List two methods by which primary productivity is accomplished in the ocean. Which one is most significant? What two factors influence it?

2 Compare the biological productivity of polar, temperate, and tropical regions of the ocean.

# 14.5 OCEANIC FEEDING RELATIONSHIPS

**Define *trophic level* and discuss the efficiency of energy transfer between different trophic levels.**

Marine algae, plants, bacteria, and bacteria-like archaea are the main oceanic producers. As these producers make food (organic matter) available to the consuming animals of the ocean, it passes from one feeding population to the next. Only a small percentage of the energy taken in at any level is passed on to the next because energy is consumed and lost at each level. As a result, the producers' biomass in the ocean is many times greater than the mass of the top consumers, such as sharks or whales.

## Trophic Levels

Chemical energy stored in the mass of the ocean's algae (the "grass of the sea") is transferred to the animal community mostly through feeding. Zooplankton are *herbivores* (*herba* = grass, *vora* = eat), so they eat diatoms and other microscopic marine algae. Larger herbivores feed on the larger algae and marine plants that grow attached to the ocean bottom near shore.

The herbivores (grazers) are then eaten by larger animals, the *carnivores* (*carni* = meat, *vora* = eat). They in turn are eaten by another population of larger carnivores, and so on. Each of these feeding stages is called a **trophic** (*tropho* = nourishment) **level**.

In the ocean, individual members of a feeding population are generally larger—but not too much larger—than the organisms they eat. There are conspicuous exceptions, however, such as the blue whale. Up to 30 meters (100 feet) long, it is possibly the largest animal that has ever existed on Earth, yet it feeds mostly on krill, which have a maximum length of only 6 centimeters (2.4 inches).

## Transfer Efficiency

The transfer of energy between trophic levels is very inefficient. The efficiencies of different algal species vary, but the average is only about *2 percent*, which means that 2 percent of the light energy absorbed by algae is ultimately synthesized into food and made available to herbivores.

**FIGURE 14.19** shows the passage of energy between trophic levels through an entire ecosystem, from the solar energy assimilated by phytoplankton through all trophic levels to the ultimate consumer—humans. Because energy is lost at each trophic level, it takes thousands of smaller marine organisms to produce a single fish that is so easily consumed during a meal!

## Food Chains and Food Webs

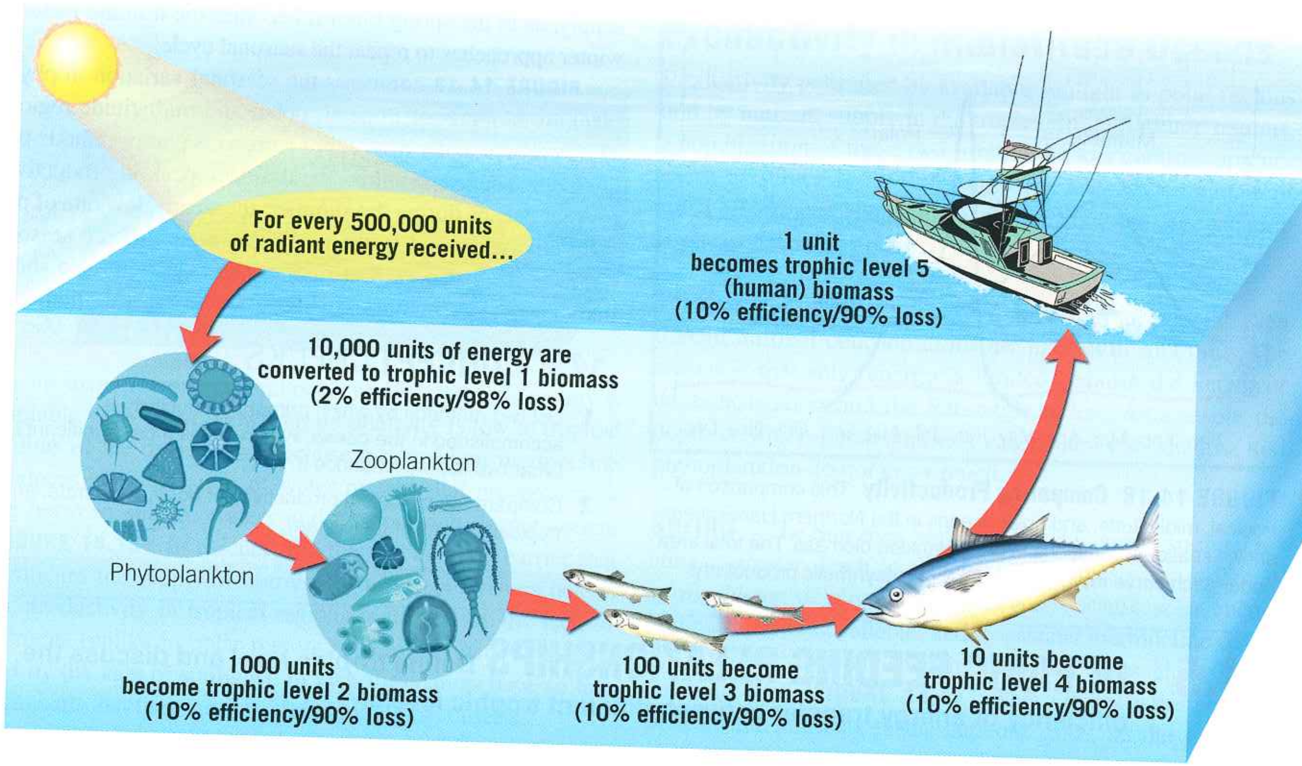
A **food chain** is a sequence of organisms through which energy is transferred, starting with an organism that is the primary producer, then an herbivore, then one or more carnivores, and finally culminating with the "top carnivore," which is not usually preyed upon by any other organism.

Because energy transfer between trophic levels is inefficient, it is advantageous for fishers to choose a population that feeds as close to the primary producing population as possible. This increases the biomass available for food and the number of individuals available to be taken by the fishery. Newfoundland herring, for example, are an important fishery that usually represents the third trophic level in a food chain. They feed primarily on small copepods that feed, in turn, on diatoms (**FIGURE 14.20A**).

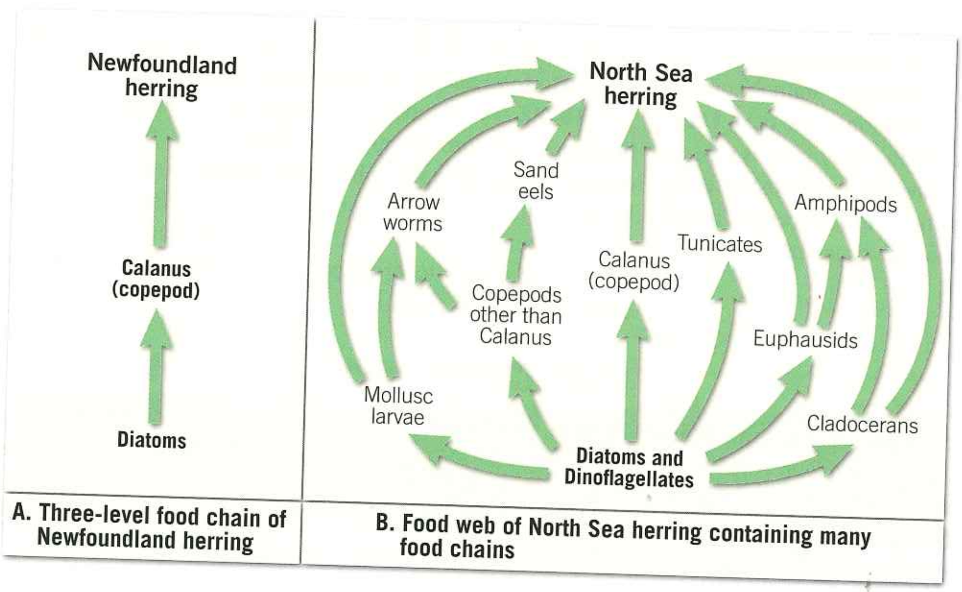
Feeding relationships are rarely as simple as that of the Newfoundland herring. More often, top carnivores in a food chain feed on a number of different animals, each of which has its own simple or complex feeding relationships. This constitutes a **food web**, as shown in **FIGURE 14.20B** for North Sea herring.

Animals that feed through a food web rather than a food chain are more likely to survive because they have

**SmartFigure 14.19 Ecosystem Energy Flow and Efficiency** For every 500,000 units of radiant energy input available to the producers (phytoplankton), only 1 unit of mass is added to the fifth trophic level (humans). Average phytoplankton transfer efficiency is 2 percent (98 percent loss), and all other trophic levels average 10 percent efficiency (90 percent loss). The ultimate effect of energy transfer between trophic levels is that the number of individuals and the total biomass decrease at successive trophic levels because the amount of available energy decreases.




**IGURE 14.20 Comparing Food Chain and a Food eb** **A.** A food chain is the ssage of energy along single path, such as om diatoms to copepods Newfoundland herring. eding relationships are ely this simple. **B.** A food b showing multiple paths food sources of the North a herring




alternative foods to eat should one of their food sources diminish in quantity or even disappear. Newfoundland herring, on the other hand, eat only copepods, so the disappearance of copepods would catastrophically affect their population.

## 14.5 CONCEPT CHECKS

1. Discuss energy transfer between trophic levels.
2. Describe the advantage that a top carnivore gains by eating from a food web rather than a food chain.

# 14 CONCEPTS IN REVIEW Ocean Water and Ocean Life

## 14.1 COMPOSITION OF SEAWATER

**Define *salinity* and list the main elements that contribute to the ocean's salinity. Describe the sources of dissolved substances in seawater and causes of variations in salinity.**

**KEY TERM:** salinity

- Salinity is the proportion of dissolved salts to pure water, usually expressed in parts per thousand (‰). The average salinity in the open ocean is about 35‰. The principal elements that contribute to the ocean's salinity are chlorine (55%) and sodium (31%). The primary sources for the elements in sea salt are chemical weathering of rocks on the continents and volcanic outgassing on the ocean floor.
- Variations in salinity are primarily caused by changing the water content of the seawater solution. Natural processes that add large amounts of freshwater to seawater and decrease salinity include precipitation, runoff from land, iceberg melting, and sea ice melting. Processes that remove large amounts of freshwater from seawater and increase salinity include the formation of sea ice and evaporation.

Michael Collier

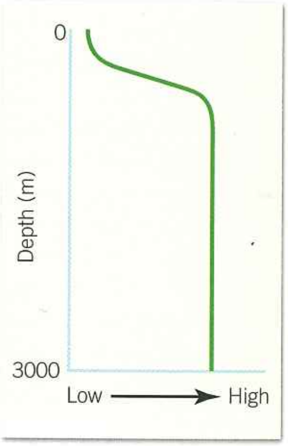
**Q How are emissions from this coal-burning power plant influencing the acidity of seawater? Explain.**

## 14.2 VARIATIONS IN TEMPERATURE AND DENSITY WITH DEPTH

**Discuss temperature, salinity, and density changes with depth in the open ocean.**

**KEY TERMS:** thermocline, density, pycnocline

- The ocean's surface temperature is related to the amount of solar energy received and varies as a function of latitude. Low-latitude regions have relatively warm surface water and distinctly colder water at depth, creating a thermocline, which is a layer of rapid temperature change. No thermocline exists in high-latitude regions because there is little temperature difference between the top and bottom of the water column. The water column is isothermal.
- Seawater density is mostly affected by water temperature but also by salinity. Cold, high-salinity water is densest. Low-latitude regions have distinctly denser (colder) water at depth than at the surface, creating a pycnocline, which is a layer of rapidly changing density. No pycnocline exists in high-latitude regions because the water column is isopycnal.
- Most open-ocean regions exhibit a three-layered structure based on water density. The shallow surface mixed zone has warm and nearly uniform temperatures. The transition zone includes a prominent thermocline and associated pycnocline. The deep zone is continually dark and cold and accounts for 80 percent of the water in the ocean. In high latitudes, the three-layered structure does not exist.




**Q Does this graph represent changes in ocean water temperature or ocean water density with depth? Does it more likely represent a location in the tropics or near the poles? Explain.**

## 14.3 THE DIVERSITY OF OCEAN LIFE

**Distinguish among plankton, nekton, and benthos. Summarize the factors used to divide the ocean into marine life zones.**

**KEY TERMS:** photosynthesis, plankton, phytoplankton, zooplankton, biomass, nekton, benthos, photic zone, euphotic zone, aphotic zone, intertidal zone, neritic zone, oceanic zone, pelagic zone, benthic zone, abyssal zone

- Marine organisms can be classified into one of three groups, based on habitat and mobility. Plankton are free-floating forms with little power of locomotion, nekton are swimmers, and benthos are bottom dwellers. Most of the ocean's biomass is planktonic.
- Three criteria are frequently used to establish marine life zones. Based on availability of sunlight, the ocean can be divided into the photic zone (which includes the euphotic zone) and the aphotic zone. Based on distance from shore, the ocean can be divided into the intertidal zone, the neritic zone, and the oceanic zone. Based on water depth, the ocean can be divided into the pelagic zone and the benthic zone (which includes the abyssal zone).

Arterra Picture Library/Alamy

**Q If you were a commercial fisher, in which of these marine life zones would you concentrate your efforts—intertidal, neritic, or oceanic? Explain.**

## 4.4 OCEANIC PRODUCTIVITY

**Contrast ocean productivity in polar, midlatitude, and tropical settings.**

**Y TERM:** primary productivity

Primary productivity is the amount of carbon fixed by organisms through the synthesis of organic matter using energy derived from solar radiation (photosynthesis) or chemical reactions (chemosynthesis). Chemosynthesis is much less significant than photosynthesis in worldwide oceanic productivity. Photosynthetic productivity in the ocean varies due to the availability of nutrients and amount of solar radiation.

Oceanic photosynthetic productivity varies at different latitudes because of seasonal changes and the development of a thermocline. In polar oceans, the availability of solar radiation limits productivity even though nutrient levels are high. In tropical oceans, a strong thermocline exists year-round, so the lack of nutrients generally limits productivity. In midlatitude oceans, productivity peaks in the spring and fall and is limited by the lack of solar radiation in winter and by the lack of nutrients in summer.

## 14.5 OCEANIC FEEDING RELATIONSHIPS

**Define *trophic level* and discuss the efficiency of energy transfer between different trophic levels.**

**KEY TERMS:** trophic level, food chain, food web

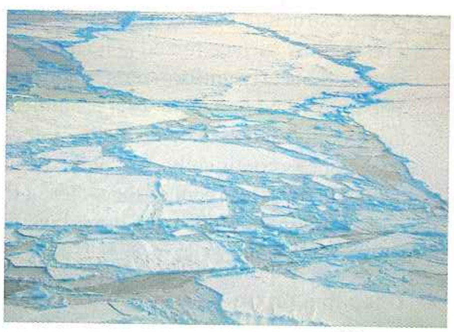
- The Sun's energy is utilized by phytoplankton and converted to chemical energy, which is passed through different trophic levels. On average, only about 10 percent of the mass taken in at one trophic level is passed on to the next. As a result, the size of individuals increases but the number of individuals decreases with each trophic level of a food chain or a food web. Overall, the total biomass of populations decreases at successive trophic levels.

Jupiterimages/Getty Images

**Q What trophic level is represented by the person in this photo?**

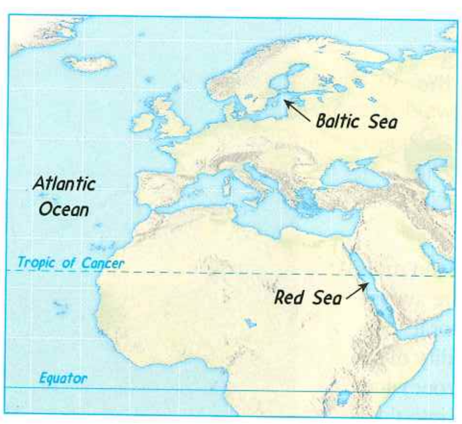
# IVE IT SOME THOUGHT

The accompanying photo shows sea ice in the Beaufort Sea near Barrow, Alaska. How do seasonal changes in the amount of sea ice influence the salinity of the remaining surface water? Is water density greater before or after sea ice forms? Explain.



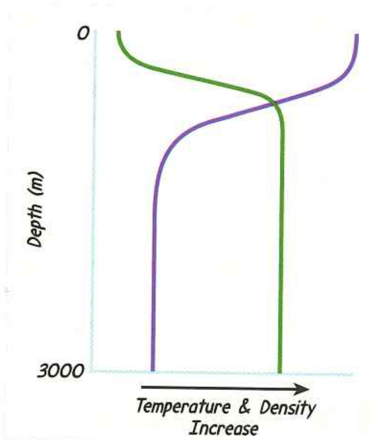
Michael Collier

Say that someone brings several water samples to your laboratory. His problem is that the labels are incomplete. He knows samples A and B are from the Atlantic Ocean and that one came from near the equator and the other from near the Tropic of Cancer. But he does not know which one is which. He has a similar problem with samples C and D. One is from the Red Sea and the other is from the Baltic Sea. Applying your knowledge of ocean salinity, how would you identify the location of each sample? How were you able to figure this out?




You are swimming in the open ocean near the equator. The thermocline in this location is about 1° C per 50 meters of depth. If the sea surface temperature is 24° C, how deep must you dive before you encounter a water temperature of 19°C?

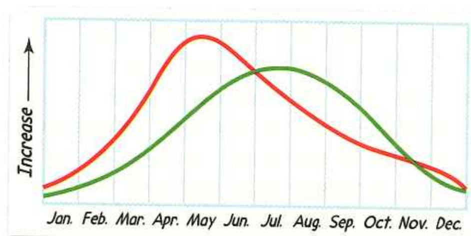
4. The accompanying graph depicts variations in ocean water density and temperature with depth for a location near the equator. Which line represents temperature and which represents density? Explain.




5. After sampling a column of water from the surface to a depth of 3000 meters (nearly 10,000 feet), a colleague aboard an oceanographic research vessel tells you that the water column is *isopycnal*. What does this mean? What conditions create such a situation? What would have to happen in order to create a pycnocline?

6. Tropical environments on land are well known for their abundant life; rain forests are an example. By contrast, biological productivity in tropical oceans is meager. Why is this the case?

7. The accompanying graph relates to the abundance of ocean life (productivity) in a polar region of the Northern Hemisphere. Which line represents phytoplankton, and



which represents zooplankton? How did you figure this out? Why are the curves so low from November through February?

8. Refer to Figure 14.19. What is the average efficiency of energy transfer between trophic levels? Use this efficiency to determine how much phytoplankton mass is required to add 1 gram of mass to a killer whale, which is a third-level carnivore.

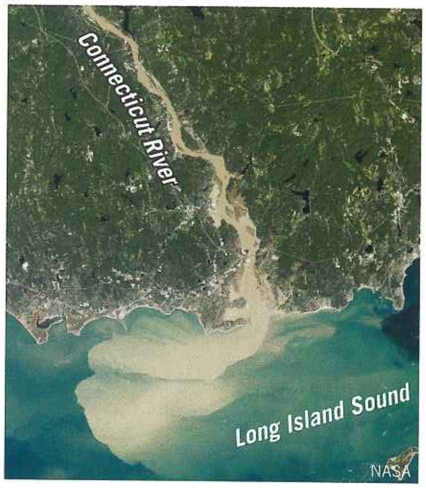
9. How might the removal of the top carnivore affect a food web? How would the removal of the primary producer affect the food web? Which change would be more significant?

# EXAMINING THE **EARTH SYSTEM**

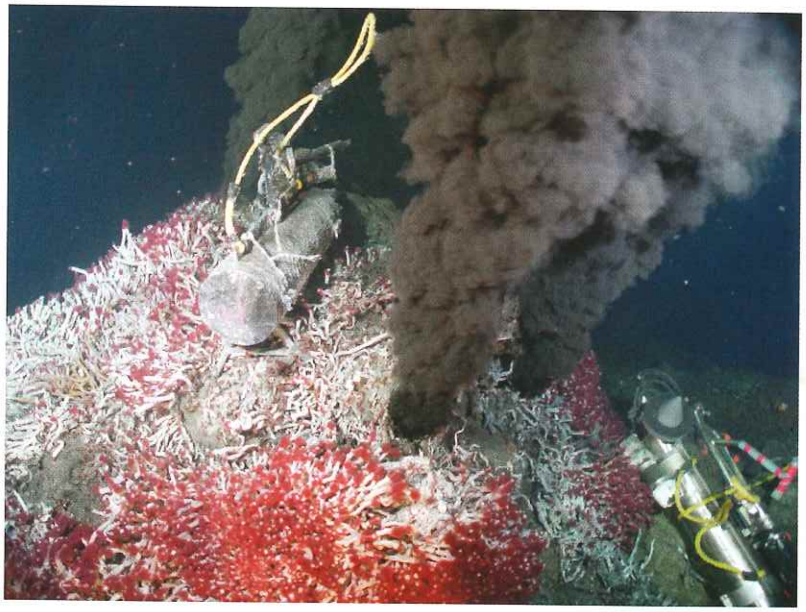
1. Reef-building corals are tiny invertebrate colonial animals that live in warm, sunlit marine environments. They extract calcium carbonate from seawater and secrete an external skeleton. Although individuals are small, colonies are capable of creating massive reefs. Many other organisms also make the reef structure their home. Corals are a part of the biosphere that inhabit the hydrosphere. The solid calcium carbonate reefs they build may ultimately become the sedimentary rock limestone, a part of the geosphere. Can you relate coral reefs to the atmosphere? Can you come up with more than one connection? Explain.

Dirscherl Reinhard/AGE Fotostock

2. A storm near the coast produces sediment-rich runoff that causes water in the euphotic zone to become cloudy. Describe how this would affect the plankton, nekton, and benthos.




3. Hydrothermal vents, such as the one shown here, occur on the ocean floor along mid-ocean ridges. The GEOgraphics in this chapter on (page 442) examined these features, where very hot, mineral-rich water is emitted into the cold water of the deep-ocean environment.
   a. What category of sediment is created by the process described above—hydrogenous, biogenous, or terrigenous?
   b. How are hydrothermal vents related to the biosphere? How can there be life in these deep, cold, and dark environments? Explain.



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