15.3 Oceanic Productivity

Reading Focus

Key Concepts
- What factors influence a region's photosynthetic productivity?
- Describe the transfer efficiency between trophic levels.
- What advantage do organisms in a food web have over those in a food chain?

Vocabulary
- primary productivity
- photosynthesis
- chemosynthesis
- trophic level
- food chain
- food web

Reading Strategy
Identifying Main Ideas Copy the table below. As you read, write the main idea of each topic.

Topic	Main Idea
Productivity in polar oceans	a. __?__
Productivity in tropical oceans	b. __?__
Productivity in temperate oceans	c. __?__

Like other ecosystems on Earth, organisms in the marine environment are interconnected through the web of food production and consumption. Marine producers include phytoplankton, larger algae such as seaweeds, and bacteria. Consumers include crabs, clams, sea stars, fish, dolphins, and whales. 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

Primary productivity is the production of organic compounds from inorganic substances through photosynthesis or chemosynthesis. **Photosynthesis** is the use of light energy to convert water and carbon dioxide into energy-rich glucose molecules. **Chemosynthesis** is the process by which certain microorganisms create organic molecules from inorganic nutrients using chemical energy. Bacteria in hydrothermal vents use hydrogen sulfide as an energy source. Acting as producers, these bacteria support the hydrothermal vent communities.

Two factors influence a region's photosynthetic productivity: the availability of nutrients and the amount of solar radiation, or sunlight. Primary producers need nutrients such as nitrogen, phosphorus, and iron. Lack of nutrients can be a limiting factor in productivity. 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 the availability of solar energy due to seasonal changes.

Section 15.3

1 FOCUS

Section Objectives

15.9 **List** the factors that influence a region's photosynthetic productivity.

15.10 **Describe** the transfer of energy from one trophic level to another.

15. 11 **Compare and contrast** food webs and food chains.

Reading Focus

Build Vocabulary L2

Paraphrase Help students understand the terms *primary productivity* and *trophic level* by explaining their meanings using words students are already familiar with. *Primary productivity* can be described as the amount of light (or chemical) energy that is turned into food by producer organisms. The term *trophic* refers to nutrition, and *trophic level* refers to the amount of food energy available to organisms at each step in a food chain.

Reading Strategy L2

a. Phytoplankton peaks in May, and zooplankton peaks in July and August; limited by availability of solar energy.
b. limited by lack of nutrients because of permanent thermocline that prevents mixing of warm surface water with colder, deeper water
c. lowest in winter and summer, higher in fall, highest in summer; limited by solar energy in winter and fall, by nutrients in summer and spring

2 INSTRUCT

Primary Productivity

Build Science Skills L2

Compare and Contrast Have students describe the similarities and differences of photosynthesis and chemosynthesis. *(Similarities: Both produce energy-rich glucose molecules. Differences: Photosynthesis uses light and is used by most producer organisms; chemosynthesis uses inorganic molecules from the environment and is limited to bacteria in hydrothermal vent communities.)*
Logical, Verbal

Section 15.3 (continued)

Use Visuals L1

Figure 13 Explain to students that this graph shows the relative numbers of phytoplankton and zooplankton biomass over time. Inform students that biomass data represents the total mass of the organisms sampled. Ask: **Biomass data on what phytoplankton organism is given in this graph?** *(diatoms)* **During what season does the phytoplankton biomass reach its peak?** *(spring)* **During what season does the zooplankton biomass reach its peak?** *(summer)*
Visual

Build Science Skills L2

Infer After students examine Figure 13, ask: **Why is there a lag time between the peak biomass of phytoplankton and the peak biomass of zooplankton?** *(Zooplankton feed on phytoplankton. Zooplankton that are able to obtain plenty of food will reproduce, creating more zooplankton. As long as there are plenty of phytoplankton, the zooplankton will continue to increase in numbers.)*
Visual, Logical

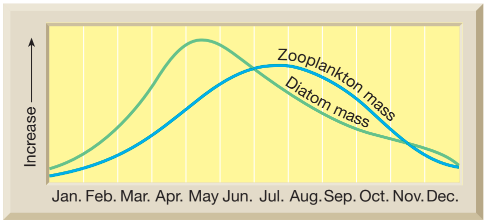


Figure 13 One example of productivity in polar oceans is illustrated by the Barents Sea. **Interpreting Diagrams** ***Describe the relationship between the zooplankton and phytoplankton populations.***

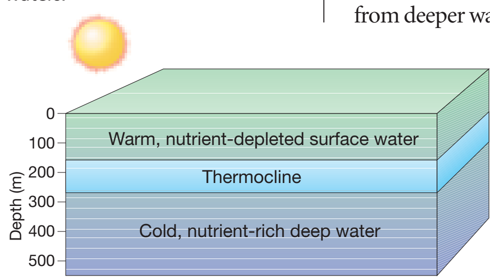
Productivity in Polar Oceans Polar regions such as the Arctic Ocean's Barents Sea, off the northern coast of Europe, experience continuous darkness for about three months of winter and continuous illumination for about three months during summer. Productivity of phytoplankton, mostly single-celled algae called diatoms, peaks there during May. This trend is shown in the graph in Figure 13. During May the sun rises high enough in the sky so that sunlight penetrates deep into the water. As soon as the diatoms develop, zooplankton begin feeding on them. As Figure 13 shows, the zooplankton biomass peaks in June and continues at a relatively high level until winter darkness begins in October.

Recall that density and temperature change very little with depth in polar regions and mixing occurs 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 lack of mixing between water masses 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, is what limits photosynthetic productivity in polar 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 oceans than in temperate and polar waters. Solar energy also is available year-round. However, productivity is low because a permanent thermocline prevents mixing between surface waters and nutrient-rich deeper waters. Figure 14 shows how water masses are separated in the tropics. The thermocline is a barrier that cuts off the supply of nutrients from deeper waters below. **Productivity in tropical regions is limited by the lack of nutrients.** These areas have so few organisms that they are considered biological deserts.

Figure 14 Water Layers in the Tropics The permanent thermocline in tropical oceans prevents the mixing of surface and deep water masses. Productivity is limited by the amount of nutrients in surface waters.



Customize for English Language Learners

Help students understand the biological terms in this section by having them explore word parts and word roots. Explain that the term *productivity* is related to the word "produce." Have students look up the definitions of *product, producer,* and *produce.* Explain to students that the suffix -*synthesis* is a word that implies the meaning "to put together." *Trophic* means "of or relating to nutrition."

Productivity in Temperate Oceans Productivity is limited by available sunlight in polar regions and by nutrient supply in the tropics. **In temperate regions, which are found at mid-latitudes, a combination of these two limiting factors, sunlight and nutrient supply, controls productivity.** These relationships are shown in Figure 15.

- **Winter** Productivity in temperate oceans is very low during winter, even though nutrient concentration is highest at this time. The reason is that solar energy is limited because days are 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. The thermocline traps algae in the euphotic zone. 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 in temperate parts of the ocean continue to warm. A strong seasonal thermocline is created that prevents the mixing of surface and deeper waters. So nutrients depleted from surface waters cannot be replaced by those from deeper waters. Throughout summer, the phytoplankton population remains relatively low.
- **Fall** Solar radiation decreases in the fall as the sun moves lower in the sky. 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. The fall bloom is very short-lived because sunlight becomes the limiting factor as winter approaches to repeat the seasonal cycle.

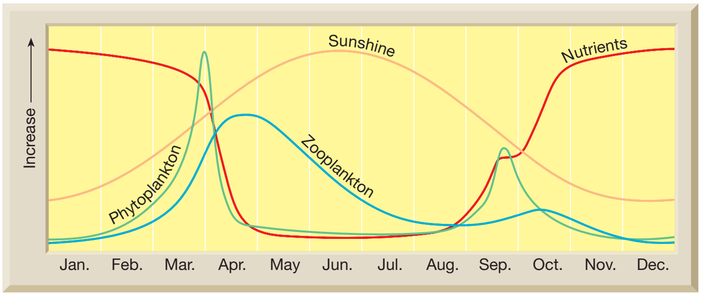


Figure 15 Productivity in Northern Hemisphere, Temperate Oceans The graph shows the relationship among phytoplankton, zooplankton, amount of sunshine, and nutrient levels for surface waters. **Analyzing** ***What happens to phytoplankton in the spring and in the fall?***

Build Reading Literacy **L1**

Refer to **p. 186D** in **Chapter 7**, which provides the guidelines for this reading strategy.

Relate Text and Visuals As students read each bulleted text section on this page, have them relate the information to the data plotted on the graph in Figure 15. First, ask students to identify which months on the *y*-axis of the graph represent the season under discussion. *(Example: winter, approximately November–February)* Then ask students to explain how the lines on the graph correspond to the information in the text. *(winter: Nutrient levels are higher than all other seasons, productivity lower than all other seasons.)* Finally, ask students to describe how they could use the graph to explain whether productivity is limited by nutrients or by sunlight. *(winter: Plenty of nutrients are available, so sunshine must be the limiting factor.)*
Verbal, Visual

Build Science Skills **L2**

Using Tables Have students use the information on this page to create a table that shows whether sunlight or nutrient availability is the principle limit of productivity at each season of the year in temperate oceans.

Season	Productivity Limited by
spring	nutrients
summer	nutrients
fall	sunlight
winter	sunlight

Logical

Facts and Figures

Earth's average surface temperature has been increasing over the past 130 years, likely as a result of human activities that increase carbon dioxide (CO_2) in the atmosphere. Stimulating a rise in ocean productivity has been suggested as a way of removing CO_2 from the atmosphere, because phytoplankton convert CO_2 to carbohydrates and oxygen. Increasing the number of photosynthetic ocean organisms would increase the amount of CO_2 removed from the atmosphere.

Iron has been identified as the nutrient that limits productivity in some ocean regions. Tests conducted in the Pacific Ocean showed that adding finely ground iron increases productivity up to 30 times. Some scientists fear that fertilizing with iron could upset the ocean's natural chemical balance and alter the global marine ecosystem. Others claim that stimulating productivity is a promising solution for helping to reduce atmospheric CO_2.

Answer to . . .

Figure 13 *As phytoplankton biomass increases, zooplankton biomass also increases, but only after a time lag.*

Figure 15 *The population of phytoplankton blooms in both the spring and fall, with the spring bloom being more pronounced.*

Section 15.3 (continued)

Oceanic Feeding Relationships

Address Misconceptions L2

Students may think that higher trophic levels actually contain more energy than lower trophic levels because they may reason that energy accumulates as you move up a food chain. Emphasize that the solar energy absorbed by producers is the only energy available to all the succeeding levels of the food chain. Ask students to think about what happens to the solar energy that the producers of a food chain convert into food molecules. *(Part of the food energy is used by the plant to make more food, absorb water and nutrients from the soil, transport materials from one part of a plant to another, and so on. Part of the food energy is consumed by organisms on the next level of the food chain.)* Challenge students to describe how this process could result in an increase in net energy as you move up the levels of a food chain. *(It cannot. Energy is used to make new cells and conduct other life processes, but no energy is added.)*

Teacher Demo

Creating an Energy Pyramid L2

Purpose Students will observe how total available energy decreases at succeeding levels of a food chain.

Procedure Draw a large pyramid shape on the board. Draw four horizontal lines across the pyramid to create five trophic levels. In each level, write the number of units of energy available as given in Figure 16. Write names of the organisms that make up each trophic level. Ask for students input as you create an energy pyramid for the organisms as shown in the food web in Figure 17. Instead of numbers, each level of this pyramid should contain the names of organisms belonging to that level.

Expected Outcome Students should see that the shape of the pyramid is a visual representation of the decrease in available energy at higher levels of a food chain or food web.
Visual, Logical

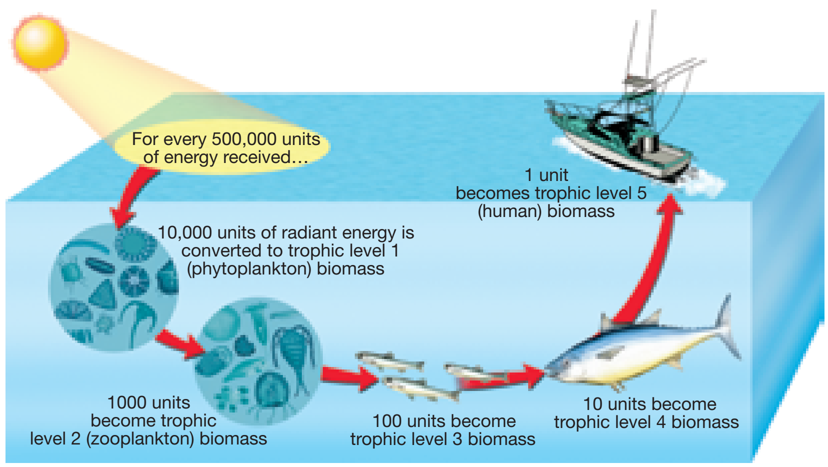
Oceanic Feeding Relationships

Marine algae, plants, bacteria, and bacteria-like organisms are the main oceanic producers. As producers make food available to the consuming animals of the ocean, energy 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 top consumers, such as sharks or whales.

Trophic Levels Chemical energy stored in the mass of the ocean's algae is transferred to the animal community mostly through feeding. Zooplankton are herbivores (*herba* = grass, *vora* = eat), so they eat algae. Larger herbivores feed on the larger algae and marine plants that grow attached to the ocean bottom near shore. The herbivores are then eaten by carnivores (*carni* = meat, *vora* = eat). Smaller carnivores are eaten by another population of larger carnivores, and so on. Each of these feeding stages is called a **trophic level.**

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. This means that 2 percent of the light energy absorbed by algae is ultimately changed into food and made available to herbivores. Figure 16 shows the passage of energy between trophic levels through an entire ecosystem—from the solar energy used by phytoplankton to a top-level carnivore, humans.

Figure 16 Energy Flow and Transfer Efficiency in an Ecosystem For every 500,000 units of radiant energy input available to the producers, only one unit of mass is added to the fifth trophic level.
Analyzing ***What is the average transfer efficiency for phytoplankton? What is it for all of the other trophic levels?***



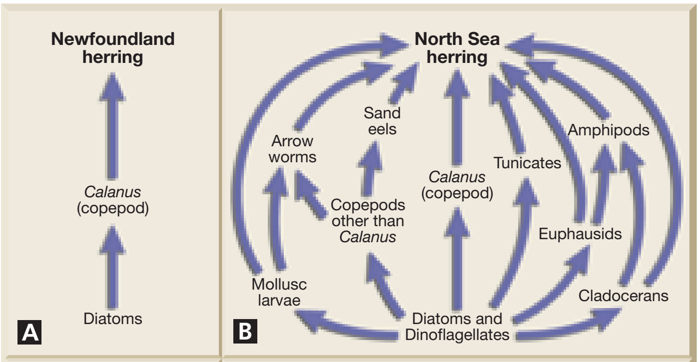
Facts and Figures

Generally, individual members of a feeding population are larger, but not too much larger, that the organisms they eat. There are conspicuous exceptions, however, such as the blue whale. Up to 30 m long, the blue whale is possibly the largest animal that has ever existed on Earth. Yet it feeds mostly on krill—shrimp-like crustaceans—that have a maximum length of only 6 cm.

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

Figure 17A shows a simple food chain. Feeding relationships are rarely as simple as this food chain suggests. More often, top carnivores in a food chain feed on a number of different animals, each of which feeds on a variety of organisms. These feeding relationships form a **food web,** as shown in Figure 17B for North Sea herring.

Animals that feed through a food web rather than a food chain are more likely to survive because they have alternative foods to eat should one of their food sources diminish or disappear. Newfoundland herring, on the other hand, eat only copepods, so the disappearance of copepods would greatly affect their population.



A food chain is the passage of energy along a single path.

A food web is more complex with many organisms interacting and depending on each other.

Figure 17 A A food chain is the passage of energy along a single path. **B** A food web is a complex series of feeding relationships with many organisms interacting and depending on each other.

Section 15.3 Assessment

Reviewing Concepts

1. What factors influence a region's photosynthetic productivity?
2. Describe the transfer efficiency between trophic levels.
3. What advantage do organisms in a food web have over those in a food chain?
4. What limits primary productivity in tropical oceans? Why?

Critical Thinking

5. **Comparing and Contrasting** Compare and contrast photosynthesis and chemosynthesis. Give examples of organisms that undergo each process.
6. **Drawing Conclusions** Explain why producers are always the first tropic level in a food chain or food web.

Math Practice

7. If 700,000 energy units are received by phytoplankton in the ocean surface, how many energy units will reach a consumer that is on the fourth trophic level of a food chain?

Build Science Skills L2

Using Models Have students work individually to research and draw a food chain from the same intertidal or coral reef ecosystem. Then have students work as a class to see how their food chains fit together to form a food web.
Logical, Visual

3 ASSESS

Evaluate Understanding L2

To assess students' knowledge of section content, have them write a paragraph explaining how energy is transferred from one level of a food web to another.

Reteach L1

Ask each student to write ten questions about the content of this section and create a separate answer key. Encourage students to use their questions to quiz each other.

Math Practice

Solution
7. 14 energy units

Section 15.3 Assessment

1. sunlight and nutrient availability
2. very inefficient, as little as 2 percent
3. Organisms in a food web have alternative foods to eat if one of their food sources diminishes or disappears.
4. the availability of nutrients; solar energy is available year-round but nutrients are trapped in deeper waters because the permanent thermocline prevents mixing between surface water and deeper water.
5. Both are examples of primary production. Energy-rich chemical compounds are the energy source for chemosynthesis. Light is the energy source for photosynthesis. Diatoms undergo photosynthesis, bacteria at hydrothermal vents undergo chemosynthesis.
6. Producers are organisms that are able to use light or chemical energy to produce glucose. Consumers cannot produce their own food and rely on producers as a food source.

Answer to . . .

Figure 16 *2 percent, 10 percent*

How the Earth Works

1 FOCUS

Objectives

In this feature, students will
- describe the conditions in each of the ocean's vertical zones.
- identify the special features and phenomena that allow organisms to survive in the different vertical zones.
- explain how atolls are formed.

Reading Focus

Build Vocabulary **L2**

Define Terms Write *bioluminescence, eyespots, hydrothermal vents,* and *coral reef* on the board. Have students review the material on this page and the next to define each term. Then discuss how each feature or phenomenon supports ocean life.

2 INSTRUCT

Bellringer **L2**

Ask students to name as many organisms as they can that live in the ocean. Make a list of all of these organisms on the board.
Logical

Use Visuals **L1**

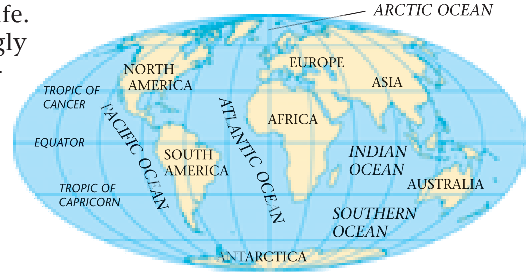
Have students examine the chart of vertical zones on this page. Ask: **How many of those organisms did you name in the Bellringer activity?** Then have them list the animals they do not know. Discuss with the class the possible reasons certain animals are less familiar than others. *(Sample answer: Animals that live deeper in the ocean are not seen in aquariums or zoos.)*
Visual

How the Earth Works

Ocean Life

The world's oceans cover almost three quarters of the Earth's surface and are home to a vast array of life. Below the surface, the oceans become increasingly cold and dark. Even so, plants and animals, ranging in size from giant whales to microscopic floating organisms called **plankton,** thrive at every depth. Some jellyfish and turtles float or swim near the surface. Whales and squid often live in the ocean's middepths. A whole host of strange-looking creatures swim or crawl around the darkest ocean depths.

Distribution of world's major oceans

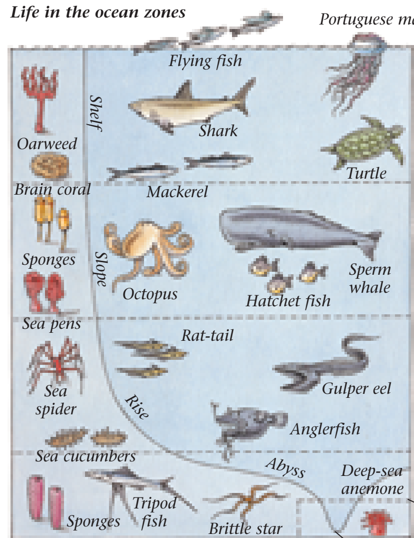


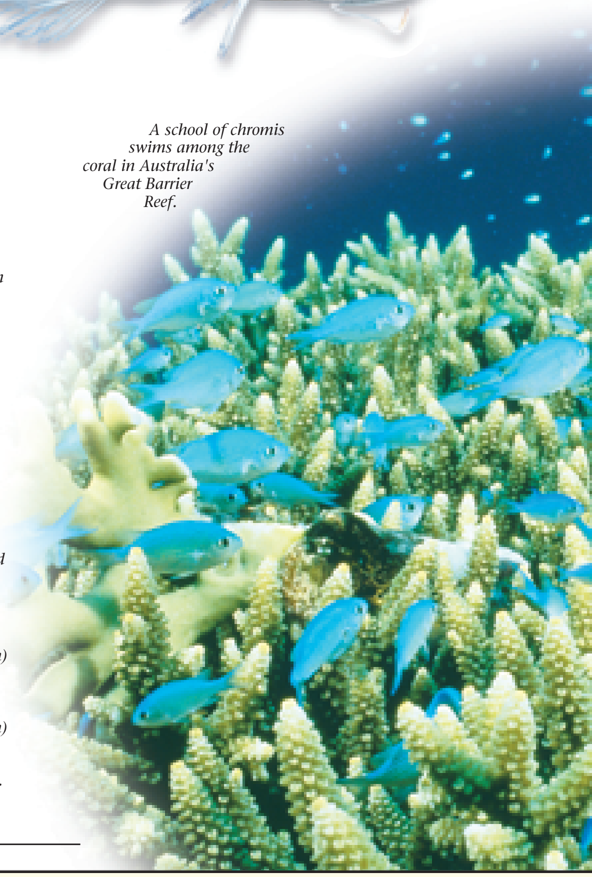
BIOLUMINESCENCE
Some fish have special organs called photophores that give off a glow. In this process, called **bioluminescence,** fish use the light to recognize members of their own species or as lures for attracting prey.

Black snaggletooth fish

VERTICAL ZONES
Oceanographers divide the oceans into zones based on depth. Each zone is home to living things that are adapted to survive at that depth. For example, deep-water animals cope with darkness, very cold temperatures, and pressures that would crush a human. Some creatures can survive in more than one zone.

Life in the ocean zones





A school of chromis swims among the coral in Australia's Great Barrier Reef.

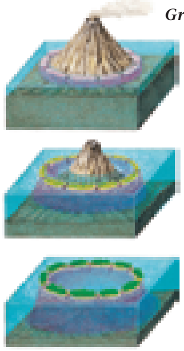
Facts and Figures

To study the deepest regions of the sea, scientists at Woods Hole Oceanographic Institute in Woods Hole, Massachusetts, use a deep submergence vehicle, or deep-sea sub, called *Alvin. Alvin* is approximately 7 m long and 3.6 m high. It can carry three scientists to a depth of 4000 m—the top of the abyss. The submersible's video equipment records life in deep ocean regions, and its manipulators, or long arms, collect specimens. In recent years, *Alvin* has helped scientists explore hydrothermal vents.

CORAL REEFS

A coral is a tubular animal with tentacles. Most corals attach to a surface and build reefs that can rise above sea level around islands and continents. Other reefs are ring-shaped **atolls** around a lagoon of shallow water. Atolls grow over millions of years.

Growth of a coral atoll



1. Coral starts to grow around a volcanic island.

2. The island sinks. Sand collects on the growing coral reef and forms land.

3. The island disappears. Vegetation grows on the atoll that remains.

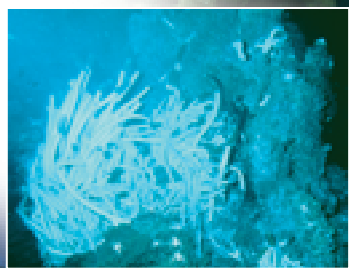
Australian sea lions are marine mammals that breathe air, feed at sea, and breed on land.

PHOTIC ZONE

Sunlight supports the growth of algae, sea grasses, and other plants on which some sea creatures feed. Marine mammals, squid, fish, and other animals have to be strong swimmers to move in the surface currents. Sea grasses and coral reefs provide food, shelter, and breeding sites for a variety of creatures.

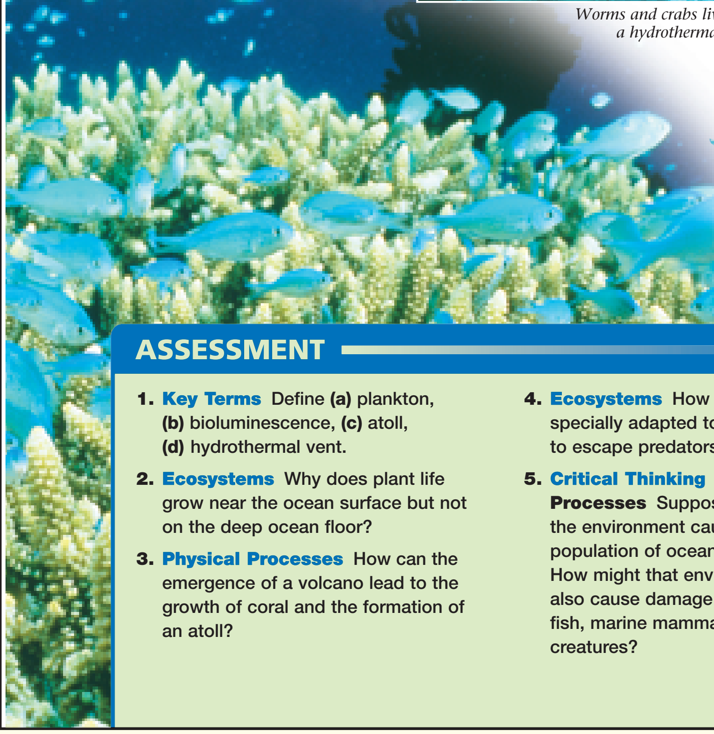
HYDROTHERMAL VENTS

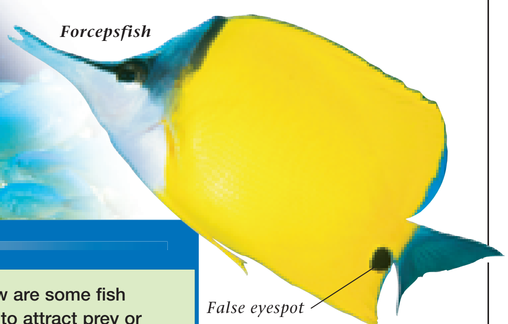
On the deep ocean floor, hot, mineral-rich water gushes from cracks, called **hydrothermal vents.** Bacteria feed on chemicals in this water, forming the basis of a food chain that does not rely on sunlight and plants. Giant tube worms, clams, and blind white crabs live around these vents.



Worms and crabs live near a hydrothermal vent.

Jellyfish can swim, but they are also influenced by ocean currents.





Forcepsfish

False eyespot

BRIGHT COLORS

Many fish have bright colors that attract mates and confuse predators. Complex coloration makes it hard to detect the outline of a fish. Some fish have eyespots, or false eyes. As a predator attacks the false head, the fish darts off in the opposite direction.

ASSESSMENT

1. **Key Terms** Define **(a)** plankton, **(b)** bioluminescence, **(c)** atoll, **(d)** hydrothermal vent.
2. **Ecosystems** Why does plant life grow near the ocean surface but not on the deep ocean floor?
3. **Physical Processes** How can the emergence of a volcano lead to the growth of coral and the formation of an atoll?
4. **Ecosystems** How are some fish specially adapted to attract prey or to escape predators?
5. **Critical Thinking** **Analyzing Processes** Suppose that changes in the environment cause a decline in the population of ocean plants and corals. How might that environmental change also cause damage to populations of fish, marine mammals, and other sea creatures?

3 ASSESS

Evaluate Understanding L2

Have students choose one of the organisms in the vertical zone chart to learn more about. Ask them to do research in the library or on the Internet to find out about the organism's features and adaptations. Have them summarize why the organism lives in its particular part of the ocean.

Reteach L1

Have students identify the world's major coral reefs and find out what steps have been taken to protect them. Have each student write a pamphlet that describes rules and regulations that visitors to reefs must obey. Post the pamphlets on a bulletin board. Discuss what students learned.

Assessment

1. (a) microscopic floating organisms; **(b)** glow given off by special fish organs called photophores; **(c)** ring-shaped coral reef around a lagoon of shallow water; **(d)** crack on deep ocean floor through which hot, mineral-rich water gushes

2. Most plant life requires sunlight for growth.

3. Coral grows around a volcanic island and as the island sinks, sand collects on the coral reef and forms land. Then vegetation grows on the atoll that remains.

4. Some fish use bioluminescence to attract prey, and many fish have eyespots or bright colors that confuse predators.

5. Such a change in the environment would disrupt the food chain and would cause fish, mammals, and other sea creatures to starve.