

UNIT  
7

MARINE  
ECOLOGY

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CHAPTER 21 *Interdependence in the Sea*

CHAPTER 22 *Pollution in the Ocean*

CHAPTER 23 *Conservation of Resources*



There are few, if any, places in the ocean where life does not exist. The place in which a group of organisms lives is called a *habitat*. The inhabitants of a place such as a coral reef or mangrove swamp form a *community*—a group of plants, animals, and other organisms that interact with one another and their environment. The study of such relationships among living things and their environment is called *ecology*. The study of such relationships in the ocean environment is called *marine ecology*.

How do marine organisms interact with one another to produce a successful and thriving community? What impact do human activities have on marine life? In this unit, you will study marine ecology and the role that humans play in marine communities.



# 21 Interdependence in the Sea

When you have finished this chapter, you should be able to:

**IDENTIFY** important nutrient cycles in the ocean environment.

**EXPLAIN** characteristics of oceanic food chains and food webs.

**DISCUSS** the importance of symbiotic relationships in the sea.

**DESCRIBE** how succession occurs in marine environments.

## 21.1 Cycles in the Sea

## 21.2 Food Relationships in the Sea

## 21.3 Symbiosis in the Sea

## 21.4 Succession in Marine Environments

Some day you will be on your own. But you will not be completely independent. You will depend on others to help you meet your needs, and people will depend on you, too. You will need to get a job in order to provide food, clothing, and shelter for yourself and your family. Your employer will pay you a salary. Medical and dental care also may be provided. There will be other expenses that you will have to pay. Life consists of such relationships in which individuals interact with one another.

In the marine world, there are also many relationships among organisms. A relationship in which organisms interact in a mutually dependent way is called *interdependence*. Some relationships are based on the need for food. In other relationships, organisms group together for mutual protection, such as fish swimming in a school. Yet, not all interdependent relationships are mutually beneficial. In this chapter, you will study the interactions among marine organisms to see how these relationships illustrate interdependence.

## 21.1 CYCLES IN THE SEA

Humans have long used natural resources, although not always wisely. Some of these resources—such as trees, minerals, topsoil, fish—have been seriously depleted because they or the products made from them have been used up or discarded. However, we can learn an important lesson from nature. There are processes in the natural world that help conserve resources. One of these processes involves the recycling of materials. Recycling is a way of conserving natural resources by using them over and over again. Many substances in the marine environment are naturally recycled, too.

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### Marine Ecology

Imagine that you are on a field trip exploring tide pools along a rocky coast. In such an environment, you could find snails, mussels, sea stars, and fish in the water. And there would be seaweed clinging to the rocks. The tide pool is like a miniature ocean, where you can observe the activities of living things in their habitat. The study of the interactions of living things with each other and their environment is called **ecology**. The study of such interactions within the ocean is called **marine ecology**.

The living things in the environment are called **biotic factors**. The biotic factors would include all the organisms in the tide pool. These organisms require the proper environmental conditions to carry out their life functions. The nonliving factors in the environment are called **abiotic factors**. Some abiotic factors in the tide pool are the water, temperature, sunlight, minerals, substrate, and dissolved gases. Together, the interacting biotic and abiotic factors within an environment make up an **ecosystem**.

Within an ecosystem, many resources are recycled. Algae use energy from sunlight, along with carbon dioxide and water, to perform photosynthesis and produce food. You may recall that organisms, such as algae, that make food are called *producers*. In turn, the algae are eaten by snails. Animals that eat other organisms are called *consumers*. The snail, sea star, mussel, and fish in the tide pool are consumers. All producers and consumers need certain nutrients that cycle through the ecosystem. Among the most important nutrients

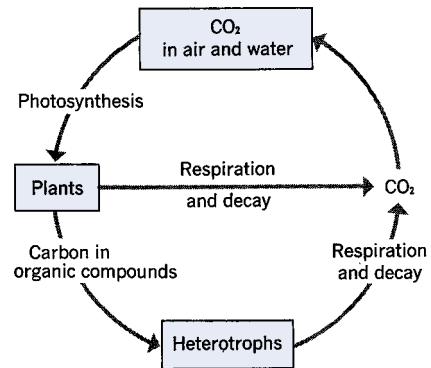
that are naturally recycled are carbon, oxygen, nitrogen, sulfur, and phosphorus.

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## The Carbon Cycle

By definition, organic compounds contain the element carbon. Photosynthesizing plants and algae take in carbon, in the form of carbon dioxide (an inorganic compound), and produce carbohydrates (organic compounds). Animals take in carbon compounds when they eat plants. Animals give off this carbon, again in the form of carbon dioxide, as a waste product of cellular respiration. This carbon then becomes available to plants for photosynthesis. The movement of carbon through living things in an ecosystem is called the *carbon cycle*. (See Figure 21-1.) In the marine environment, the carbon in dissolved carbon dioxide may be taken up by plants and by animals (such as corals and mollusks) and combined with the calcium in seawater to produce calcium carbonate shells and body parts. The carbon in these organisms is released into the marine environment when the organisms die and decay.

**Figure 21-1** The carbon cycle.

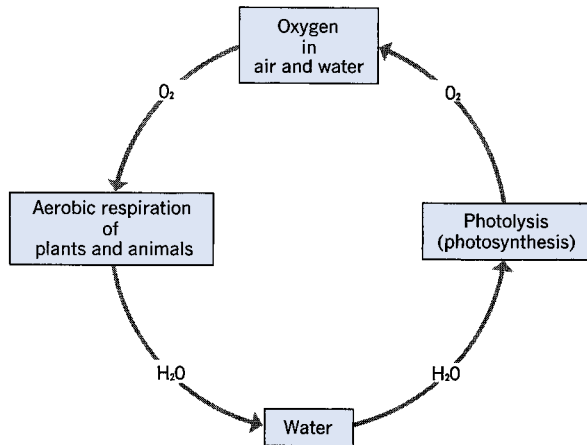


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## The Oxygen Cycle

Oxygen is the crucial element needed for cellular respiration in both plants and animals. Plants (and algae) release oxygen into the atmosphere when they split water molecules during photosynthesis. Animals, as well as plants, take in oxygen to use in respiration. Just

Figure 21-2 The oxygen cycle.



as plants need the carbon dioxide that animals give off, animals depend on the release of oxygen by photosynthesizing plants and algae. This movement of oxygen molecules between plants (algae) and animals is called the *oxygen cycle*. (See Figure 21-2.) Together, the carbon and oxygen cycles are often referred to as the *carbon dioxide–oxygen cycle*. Oxygen is also involved in the cycles of other nutrients in the environment, such as nitrogen, phosphorus, sulfur, and silicon.

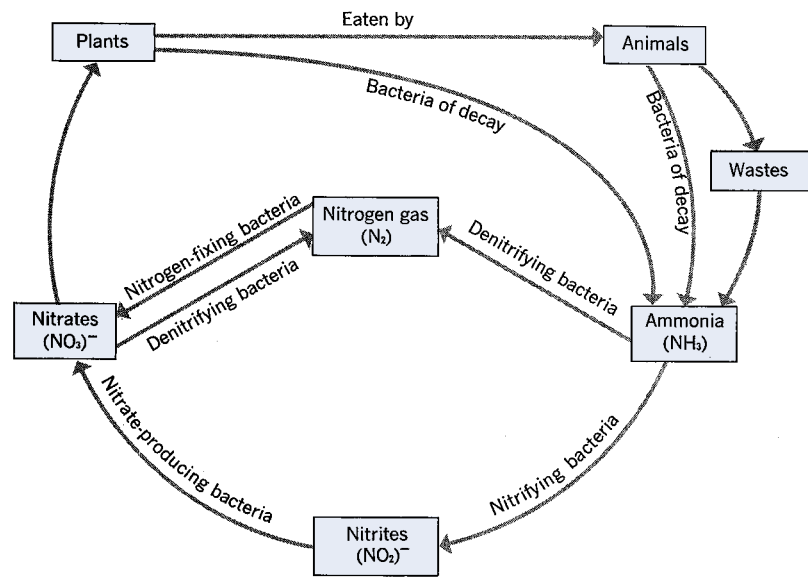
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## The Nitrogen Cycle

All living things grow. To grow, animals and plants must make chemical substances called *proteins*. Important proteins include hemoglobin, myoglobin, enzymes, and hormones. The main elements that combine to form proteins are carbon (C), hydrogen (H), oxygen (O), and nitrogen (N). The formation of proteins begins with algae and plants, which produce the amino acids that build the proteins. Nitrogen, which is needed to make up the amino acids, is made available to living things in an ecosystem by a process called the *nitrogen cycle*. (See Figure 21-3 on page 520.)

Compounds that contain nitrogen, such as urea and ammonia, are excreted as metabolic wastes by animals and are used by bacteria. When plants and animals die, their bodies are decomposed by different kinds of bacteria. Decay bacteria break down the proteins in wastes and tissues and produce ammonia (NH<sub>3</sub>), a toxic compound

**Figure 21-3** The nitrogen cycle.



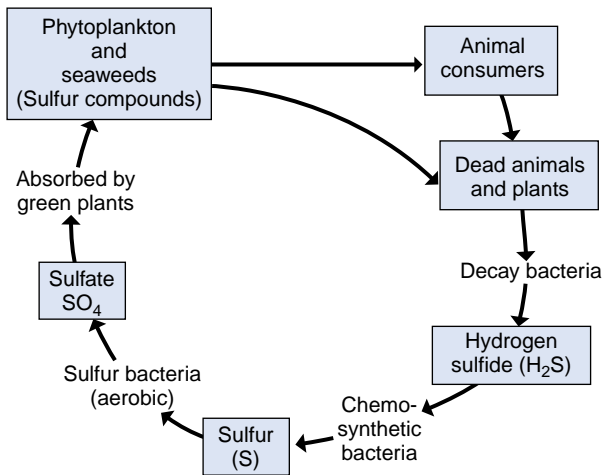
that cannot be used by plants. Some decay bacteria convert ammonia into the nontoxic ammonium ion ( $\text{NH}_4^+$ ). Denitrifying bacteria convert the ammonia into free nitrogen ( $\text{N}_2$ ), while nitrifying bacteria oxidize the ammonia to form nitrites ( $\text{NO}_2^-$ ) and then nitrates ( $\text{NO}_3^-$ ). Nitrogen-fixing bacteria, such as blue-green bacteria, also oxidize the free nitrogen to nitrates (while denitrifying bacteria reverse that process).

The process of producing nitrates from atmospheric nitrogen is called **nitrogen fixation**. Algae and marine plants are able to take up ammonium ions, nitrites, and nitrates and use them in organic compounds. The nitrogen in marine plants and algae that are eaten by animals are used to make proteins. When these plants and animals decay, their proteins are broken down and the nitrogen is recycled. Lightning in the atmosphere also converts free nitrogen in the air into usable nitrates that fall to the ground in the rain.

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## The Sulfur Cycle

Another important element that is recycled in the marine environment is *sulfur*. Many large protein molecules with long amino acid chains contain sulfur. For example, the protein hemoglobin, which binds oxygen in red blood cells, has eight sulfur atoms. The sulfur is



**Figure 21-4** The sulfur cycle.

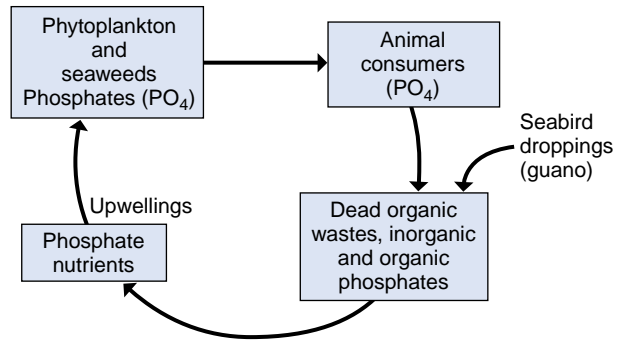
essential because it acts as a bridge that allows the molecule to bend and twist, giving it its shape.

Sulfur is recycled from dead matter in the sea back into marine plants (algae) and animals through a series of chemical reactions controlled by bacteria. This process is called the *sulfur cycle*. (See Figure 21-4.) In the first reaction, decay bacteria break down wastes into hydrogen sulfide ( $\text{H}_2\text{S}$ ). Hydrogen sulfide (which smells like rotten eggs) is toxic, so plants and algae cannot use it. Chemosynthetic bacteria convert the hydrogen sulfide into sulfur. But this form is still not suitable for absorption by algae. Special sulfur bacteria, however, convert sulfur into sulfate ( $\text{SO}_4^{2-}$ ), which is absorbed by the algae and used in the manufacture of proteins. Animals get the sulfur they need when they eat algae, plants, and other animals.

## The Phosphorus Cycle

Living things need energy to do work. Energy is found in molecules such as glucose. Inside cells, when glucose is oxidized during cellular respiration, energy is liberated and converted into a more usable form called *adenosine triphosphate*, or *ATP*. The energy in ATP is stored in its phosphate bonds, which contain the elements phosphorus and oxygen. Phosphorus is also present in deoxyribonucleic acid, or DNA, the genetic blueprint found in all living cells. Thus, without phosphorus, there is no DNA or ATP, two of the most important chemicals in living things.

**Figure 21-5** The phosphorous cycle.



Phosphorus is supplied to all living things through the *phosphorus cycle*. (See Figure 21-5.) Decay bacteria decompose dead matter on the seafloor. The molecules that contain phosphorus, such as DNA and ATP, are broken down and phosphate (PO<sub>4</sub><sup>3-</sup>), a product of decay, is released into the water. Phosphates from human activities and from natural sources such as weathered rocks and soil also enter the marine environment. Plants and algae in the ocean absorb the phosphates. Marine animals get their supply of phosphorus when they eat these plants and algae or other marine animals. Another source of phosphates for marine life is the droppings from seagulls and other seabirds. Seabirds nest along coasts and on islands, where thick deposits of their droppings accumulate. These droppings, called *guano*, are rich in phosphorus. Since phosphorus is also an important nutrient for the growth of land plants, guano is often harvested and sold as fertilizer.

## 21.1 SECTION REVIEW

1. How are the carbon cycle and the oxygen cycle interrelated?
2. Why are various bacteria so important for the nitrogen cycle?
3. How is phosphorus cycled in the marine environment?

## 21.2 FOOD RELATIONSHIPS IN THE SEA

Relationships between organisms that are based on nutritional needs are called *food relationships*. In the marine environment, just

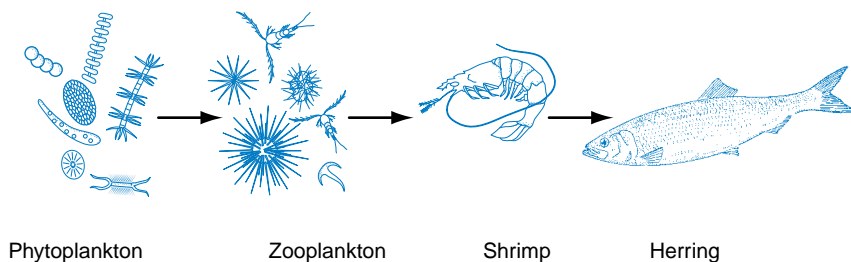
as on land, several types of food relationships can be observed. You will study some of these food relationships next.

## Food Chains

Look at the food relationship shown in Figure 21-6. This kind of relationship is called a **food chain**, because one living organism serves as food for another organism, which serves as food for the next organism in the chain. All food chains begin with a producer. As you can see in the figure, the producers are the microscopic phytoplankton. The next organism in the food chain is a consumer, usually an animal, such as the zooplankton. The zooplankton is called a **primary consumer**, since it is the first animal in the food chain. The shrimp, a **secondary consumer**, feeds on the zooplankton. In turn, the fish or the squid, a **tertiary** (third-level) **consumer**, eats the shrimp. As each organism feeds on another, there is a transfer of chemical energy—from the producer through each level in the food chain. Each feeding level is called a **trophic level**.

Food chains vary in length. All food chains must have a producer and at least one consumer. How many consumers are shown in the food chain in Figure 21-6? As you can see, there are three consumers. Consumers vary in their food requirements. Animals such as zooplankton that feed only on algae or plantlike organisms are called *herbivores*. The other animals pictured in the food chain (the shrimp and the herring) are *carnivores*. An animal that consumes both animals and plants is called an **omnivore**. Humans are omnivores, since we eat both plant and animal foods.

When producers and consumers die, their remains are eaten by scavengers and decayed by decomposers—the organisms that break down dead matter into smaller particles. The **scavengers**, such as



**Figure 21-6** Feeding levels in a marine food chain; the first organism is always a producer.

crabs and mud snails, eat the remains of already dead plants and animals. The most common of the decomposers are the bacteria, which are found everywhere in the marine environment. However, most are concentrated in the bottom sediments because the dead matter on which they feed settles there and accumulates. Some types of fungi, such as molds, are also decomposers. Another term used to describe decomposer bacteria and fungi is saprophytes.

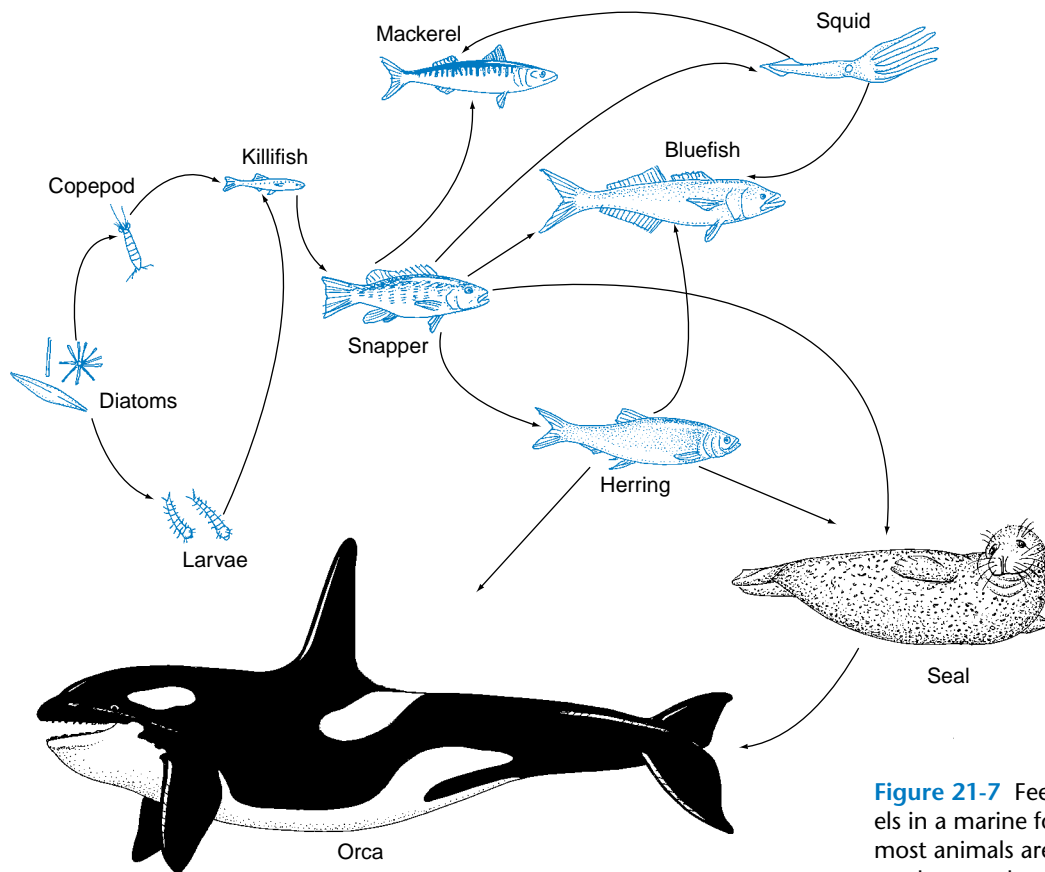
The decomposers break down the dead matter into organic molecules and simple compounds, which are taken up by the producers. This transfer of organic matter—from producers, to consumers, to decomposers, and back to producers again—“cycles” energy and nutrients through the food chain. The recycling of organic matter is the means by which all living things in the ocean can satisfy their nutritional needs.

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## Food Webs

In the ocean, many food chains are interconnected, thereby forming a giant **food web**. Look at the food web shown in Figure 21-7. The consumers vary in their relationships with one another. The producers are always at the base of the food web. Most of the consumers shown in the figure are predators; they occupy trophic levels above the primary consumers. A **predator** is an animal that kills and eats another animal. Consumers may also be scavengers, eating the remains of animals that are already dead. In addition, most of the consumers serve as prey for one or more other animals. The **prey** is the animal that is eaten by a predator. Which animals in the food web are not both prey and predator? All the animals are both predator and prey, except for copepods and mosquito larvae, which graze on diatoms, and killer whales, which are the top predators that are not preyed on by other animals.

What would happen to this food web if the mosquito larvae in a saltwater marsh were suddenly wiped out by insecticide spraying along the coasts? It might appear that the killifish would decline in number (and thus disrupt the food web) because they feed on the mosquito larvae. However, killifish have another food source, the copepods, which may sustain them. In food webs, predators often feed on more than one type of prey. This increases their ability to survive if one food source becomes scarce. In addition, predators



**Figure 21-7** Feeding levels in a marine food web; most animals are both predator and prey.

such as the killifish can be omnivores; that is, they also eat plants. However, serious disruptions to food chains and food webs—for example, those that result from El Niño or intense overfishing—have negative effects on populations of marine organisms such as seabirds and seals. Similarly, harvesting of krill in Antarctic waters for human consumption gives cause for concern, since that could have an impact on baleen whale populations. The whales are secondary consumers that feed directly on these zooplankton.

## Food Pyramids

The organisms in food chains can be arranged in a diagram called a **food pyramid**. In a food pyramid of numbers, the population at each higher trophic level is smaller than the one below it. (See

**Figure 21-8** Trophic levels in a marine food pyramid; the producers (bottom level) are highest in numbers and in concentration of food energy.

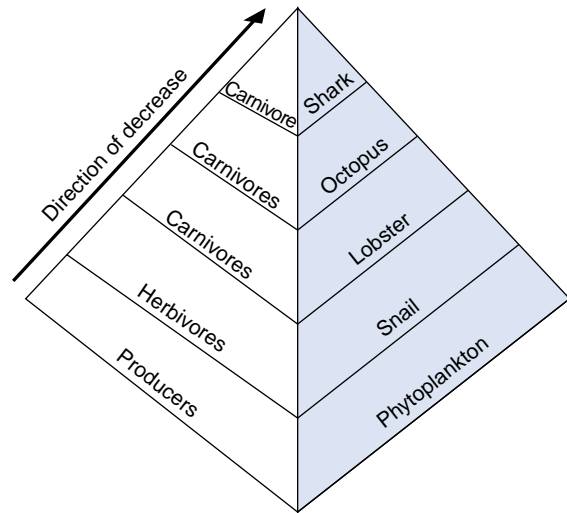


Figure 21-8.) The phytoplankton (algae and plants) outnumber the snails. There are more snails than lobsters. Lobsters are more numerous than octopuses. And sharks are the least numerous of all. In other words, each prey population outnumbers the predator population above it. What would happen if predators outnumbered their prey? Some predators would die from a lack of food. Large populations of producers and prey are needed to sustain the consumers in each higher trophic level. (At times, there may seem to be more zooplankton than phytoplankton, but the high productivity of the algae supports the continual grazing by the zooplankton.)

The food pyramid also illustrates the transfer of energy from producers through each successive trophic level of consumers. In fact, this transfer of energy explains the need for large populations of producers and prey. Which organism in Figure 21-8 possesses the highest concentration of available energy? The population of algae at the base (the largest area) of the pyramid has the highest amount of available energy. The population of sharks at the top of the pyramid has the least amount of available energy.

Why do the algae have the highest concentration of energy and sharks the lowest? At each level of consumption, a great deal of energy is lost as heat. The abundant seaweed is highest in energy because it absorbs energy directly from the sun and converts it into glucose. Some of the energy is used for the seaweed's life functions

and is lost as heat. When snails consume the seaweed, they use up most of the energy in the food (about 90 percent), while the rest of it is stored in the snail's body tissues.

Only about 10 percent of the food energy consumed by an organism is available as food to the next organism in the chain. Thus, when a lobster eats a snail, most of the energy is used for life processes and is lost as heat, while the remaining 10 percent or so is stored in the lobster's body. Consequently, as food energy is transferred from one trophic level to the next, a great amount is lost at each step. Within the pyramid, there is less energy available for consumption at the trophic level of the shark. To produce 10 kg of body matter, a shark has to eat about 100 kg of food. But that 100 kg of food was produced as a result of the consumption of 1000 kg of food, and so on. That is why the producers and lower-level consumers have to be more abundant than the organisms at higher trophic levels. So a food pyramid is a way of showing that there is more energy available at the bottom of a food chain than at the top.

## 21.2 SECTION REVIEW

1. What are the different trophic levels in a food chain?
2. Explain how an organism can be both predator and prey in a food web.
3. Why does food energy decrease with each higher trophic level?

## 21.3 SYMBIOSIS IN THE SEA

In the ocean, there is a constant struggle for existence as marine organisms avoid predators and compete for food, mates, and territories. Living things have evolved a variety of relationships that help them survive. One kind of relationship that may be beneficial to an organism is *symbiosis*. (See Chapter 7.) In symbiosis, organisms of different species live in close association with one another. There are three different types of symbiotic relationships, each with varying degrees of benefit to the parties involved but all related to feeding strategies.

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## Mutualism

Look at the symbiotic relationship shown in Figure 21-9. A clownfish lives among the stinging tentacles of a sea anemone. This special kind of symbiosis is called **mutualism**, a relationship in which both species benefit from the association. The sea anemone benefits because it can feed on scraps of food left by the clownfish and is protected by them from the nibbling of other fish. The clownfish benefits because it is protected from predators by the stinging cells in the anemone's tentacles. The mucus coating on the clownfish's skin contains a chemical inhibitor that prevents the discharge of stinging cells in the tentacles. This kind of mutually beneficial relationship is also found between other small fish and some jellyfish, and between cleaner shrimps and sea anemones. (See the photograph on page 516.)

Other examples of mutualism can be found in the sea. Many large tropical fish, such as the grouper, cannot rid themselves of the parasites that attach to their skin and gills. However, some tiny fish, such as the cleaning wrasse, feed on fungi and invertebrates that live on the fish's skin and in its body cavities. The relationship between coral polyps and the zooxanthellae (algae) that live inside them is another example of mutually beneficial symbiosis. Both

**Figure 21-9** The clownfish and sea anemone have a symbiotic relationship called mutualism.



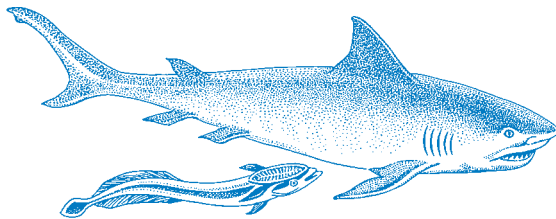
organisms benefit because the algae get a home, carbon dioxide, nitrate, and phosphate from the polyps, while the coral polyps get glucose and oxygen from the algae. Mutually beneficial zooxanthellae are also found in the mantle tissue of the giant clam *Tridacna* of the South Pacific.

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## Commensalism

In another symbiotic relationship, called **commensalism**, one species benefits while the other species is, apparently, unaffected by the association. In several species of sharks, a remora (attached by a dorsal suction disk) or a small group of pilotfish may swim below or ahead of the shark as it cruises along. (See Figure 21-10.) The small fish scavenge on leftover bits of food after the sharks have fed. The shark is neither helped nor harmed by the presence of these fish; the small fish benefit by getting a free meal.

Another commensal relationship is that of a whale and the barnacles that live on its back. The barnacles benefit by being attached to a substrate from which they can filter-feed as the whale swims through nutrient-rich waters. The whale is, for the most part, unaffected by the presence of the barnacles. Organisms such as barnacles, sea anemones, and slipper shells that attach to the bodies of larger animals without causing them harm are called *commensal organisms*.



**Figure 21-10** The shark and the remora have a symbiotic relationship called commensalism.

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## Parasitism

A third type of symbiosis, called **parasitism**, involves a relationship in which one species benefits while the other species is harmed. An organism that lives in or on another creature and feeds off its tissues

is called a *parasite*. (See Chapter 8.) The animal that is infected is called a *host*. A parasite can survive only if it is attached to its host. If the host dies, so does the parasite, unless it is able to find a new host.

Because of the loss of commercially valuable fish, parasitism can be costly to the economy. In the Great Lakes, the lake trout is in decline due to the accidental introduction of the sea lamprey, which parasitizes lake trout. (Refer to Figure 12-3, on page 283.) With its suckerlike mouth and rough tongue, the sea lamprey attaches to a trout, then scrapes a hole in the trout's skin and feeds on its body fluids. The lamprey may feed on the trout for a few hours or several days, then move on to another trout to continue feeding. The deep-sea hagfish takes its parasitism a step farther—it burrows into the bodies of larger fish and feeds on their tissues from inside.

The life cycle of a parasite often involves more than one type of host. Black spot disease is a kind of parasitism that occurs in some marine fish and is caused by a trematode, a type of flatworm. (Refer to Figure 8-1, on page 194.) Sea gulls that feed on fish with black spot disease eat the parasitic worms as well. The flatworms reproduce in the intestines of the sea gull, and the eggs are eliminated with the bird's droppings. The eggs develop into small swimming larvae in the shallow waters of the intertidal zone. The larvae then enter the first intermediate host, usually a small marine snail, where they develop into juvenile worms. They leave the snail and attach themselves to the second intermediate host, a passing fish, where they form black cysts on the skin and then mature. A serious infection can weaken the fish to the point where it dies. Sea gulls feeding on these fish consume the mature flatworms, and the cycle continues.

Although parasitism is harmful for the host involved, it is an important feature of life in animal populations. Most major groups of marine organisms have internal parasites, usually some type of flatworm. Many ocean fish (such as the grouper mentioned above) also have external parasites. These are usually tiny crustaceans, such as isopods and copepods, that attach to the host's skin and gills and obtain their nutrients from the fish's blood. Environmental conditions can also play a role in determining an animal's susceptibility to parasitism. Scientists have noticed that poor water quality increases stress in marine organisms and lowers their resistance to disease, making them more vulnerable to parasitic infections.

## 21.3 SECTION REVIEW

1. How do symbiotic relationships illustrate interdependence?
2. How does the clownfish survive among the stinging tentacles of the sea anemone? Why is that an example of mutualism?
3. Explain the kind of symbiosis that sharks and pilotfish have.

## 21.4 SUCCESSION IN MARINE ENVIRONMENTS

What was it like growing up on the street where you live? Do you remember new neighbors arriving and old friends moving away? New buildings may have been constructed on your block or others remodeled. Over time, neighbors and neighborhoods change.

Change also occurs in the marine environment. You can place a hard object, such as a rock, in a tide pool at the beach and examine it over a period of time. At first, a thin coat of algae will begin to cover the rock's surface, making it feel slimy. If you leave the rock in a tide pool long enough, you may see its coat of algae replaced by barnacles. Later on, seaweed, mussels, and other small organisms may join the barnacles that coat the rock. The same process also occurs on the hull of a boat. In fact, boats sometimes need to have their hulls scraped clean of barnacles and mussels, because they affect the vessel's movement through the water.

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### Ecological Succession

The process by which one community of organisms gradually replaces another community of living things over time is called **ecological succession**, or *biological succession*. Succession occurs in a variety of marine habitats, such as sandy beach dunes, rocky shores, and coral reefs. (See Figure 21-11 on page 532.)

What causes one community of organisms to replace another community? When the chemical and physical conditions in an area are no longer suitable for the existing life-forms, a new community

**Figure 21-11** Succession on a sandy dune: beach grasses are followed by shrubs.



of living things slowly takes over. The first group of organisms to appear in an area devoid of life—such as on a new wharf piling or new volcanic island—is called the **pioneer community**. The pioneer organisms represent the first stage in ecological succession. When the pioneering algae settle down on a rock, they begin to change their physical and chemical environment. Algae take up carbon dioxide, make their own food, and produce oxygen. Changes brought about by the algae actually favor colonization by other organisms, such as barnacles. The barnacles, in turn, alter the environment and are succeeded by a more stable community, dominated by mussels. The last stable community to appear in any succession is called the **climax community**. Each climax community has a dominant species, which is the main species that finally appears there. Marine succession varies with climate. The algae-to-barnacle-to-mussel succession occurs along temperate shores in the more northern latitudes.

In tropical seas, corals form the climax community. Coral polyps attach to any hard substrate and, over a long time, cover the substrate with a coral reef. Other organisms are attracted to the corals, slowly forming a more complex and diverse community. In fact, old sunken ships are difficult to find in tropical waters because this process of succession entombs ships under coral.

# ENVIRONMENT

## Turf Wars off Fisherman's Wharf

San Francisco is a multicultural city where people from all over the world have settled. Paralleling this influx of people from foreign lands has been the arrival of foreign, or exotic, marine species from other oceans to the waters of San Francisco Bay. But not all the inhabitants get along. Turf wars have developed between some of the native species and the exotic invaders. So far, marine biologists have identified more than 200 exotic species in the bay, and new ones continue to arrive. These organisms are usually introduced in the ballast water that is discharged daily by ships anchored in the bay. Water from the ballast tanks contains eggs and larvae of fish and invertebrates from the ports where the ships embarked. Some species arrive packed in boxes of fish bait. Crabs from China, protozoans from Japan, and a variety of species from the East Coast—including Atlantic ribbed mussels (see photograph), striped bass, and cordgrass—have found a niche in the shallow bays and inlets of the San Francisco estuary.

This great increase in species diversity has come at a price. Competition with, and predation by, the exotic fauna and flora has decreased populations of some local species. The thicktail chub, a native to the bay, has been eliminated by the influx of foreign species. Another local fish, the delta smelt, is now an endangered species. The Atlantic green crab—originally a native of Europe that “emigrated” to New England coastal waters in the 1950s and later



traveled in ballast tanks to San Francisco Bay—is a predator that attacks the juvenile Dungeness crab, a popular food item in the bay area. One exotic, a burrowing isopod from Australia, presents a different kind of problem: it tunnels into the Styrofoam blocks that support floating docks, causing them to sink. On the other hand, some of the exotic species have turned out to be valuable new food sources for the bay area.

The ultimate effects of the exotics in the bay are yet to be seen. Marine scientists think that, over time, a new ecosystem will establish itself—with a climax community of many different marine species replacing the ecological roles of former inhabitants that lost the fight for their turf off Fisherman's Wharf.

## QUESTIONS

1. Identify two exotic species in San Francisco Bay. Why are they called *exotic*?
2. How did the various exotic marine species arrive in San Francisco Bay?
3. Why are some exotic species harmful to the native bay species? Give an example.

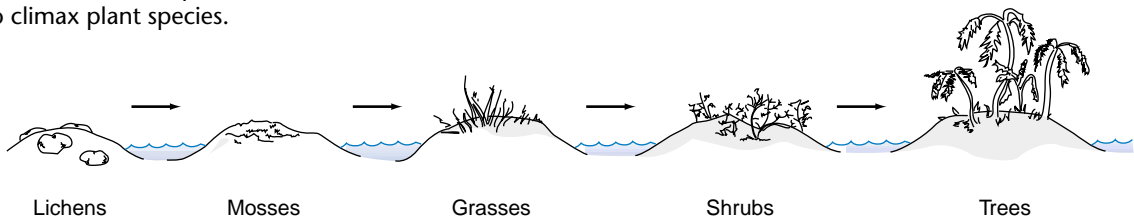
Climax communities are not necessarily permanent. Natural disturbances such as storms can strip mussels from rocks. The activities of people can have an effect, too. For example, overharvesting of mussels from rocks can wipe out a climax community. When a climax community is destroyed, the area is made available for pioneering organisms to start the process of succession over again. It takes time, perhaps many years or decades, for a new climax community to become established.

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## Succession on Islands

Succession occurs on land as well as in the sea. In areas of seismic activity, such as the South Pacific, tiny islands are born each year as molten lava from the seafloor reaches the surface and solidifies into rock. At first, these islands are devoid of life. But after the rock cools, conditions for life become more favorable. Spores and seeds arrive on the new islands, brought by winds, waves, and various animals. For example, seeds may be carried in the digestive tracts of migrating birds. The first pioneer organism to appear on barren rocks is usually lichen. The **lichen** is actually composed of two organisms, an alga and a fungus, growing together in a symbiotic relationship. Acids in the lichens erode the surface of rocks, producing a more porous surface and loose sediments that favor the growth of the next community, the mosses. Mosses carpet the surface of rocks and cause further erosion into rock particles and gravel. The loose sediments and dead plant matter create a thin soil that is favorable for the germination of grass seeds. Grasses take over and dominate the landscape for a number of years and then are succeeded by shrubs. The shrubs cause further changes in the soil that favor the growth of trees, the climax community (of plants) that will dominate the island. (See Figure 21-12.)

**Figure 21-12** Succession on an island, from pioneer to climax plant species.



## **21.4 SECTION REVIEW**

1. What causes one community of organisms to succeed another?
2. Compare one pioneer community with one climax community.
3. How does succession occur on a rocky volcanic island?

# Laboratory Investigation 21

## Observing How a Barnacle Filter-Feeds

**PROBLEM:** How does the barnacle obtain its food?

**SKILLS:** Conducting an experiment; observing the behavior of organisms.

**MATERIALS:** Live barnacles attached to substrates, bowls or shallow containers, seawater, hand lens, watch or clock, fish food (dried plankton).

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### PROCEDURE

1. Put a barnacle with its attached substrate in an empty bowl or container. Notice the overlapping shells that surround and protect the barnacle. Make a sketch of the barnacle in your notebook. Observe the barnacle closely and note if it moves or responds to the environment in any way.
2. Cover the barnacle with seawater. Wait a minute for the barnacle to respond. Notice the appendages, called *cirri*, as they extend outward and then retract into the barnacle's shells. This movement is an automatic response by the barnacle to its seawater environment.
3. Count the cirri and record the number in your notebook. Notice the hairlike bristles attached to the cirri. Use your hand lens for a close-up look. Food particles get trapped in the bristles as the cirri sweep the water. The movement of the cirri in and out of the shells is the barnacle's method of filter-feeding. Make a sketch of a filter-feeding barnacle; label all parts.
4. You can measure the automatic feeding response of the barnacle by calculating the number of times the cirri beat per minute. Count the number of times the cirri move in 15 seconds and multiply by 4 to get the number of movements per minute. Record this number in the *Automatic Response* column in your copy of Table 21-1. Try to perform six trials to obtain an average number of cirri movements per minute. (This is the control group.)

**TABLE 21-1** COMPARING FEEDING RESPONSES OF THE BARNACLE  
(MOVEMENTS/MINUTE)

Trial	Automatic Response	Response to Food
1		
2		
3		
4		
5		
6		
Total		
Average		

5. Now sprinkle some fish food in the water, near the barnacle. Again, count the movements for 15 seconds and then calculate the number per minute. Record the number in the *Response to Food* column in your copy of Table 21-1. Try to perform six trials to obtain an average number of cirri movements per minute. (This is the experimental group.) Compare the results from both sets of trials to see if there are any significant (measurable) differences.

## OBSERVATIONS AND ANALYSES

1. Does the barnacle show any feeding response when it is *not* covered with seawater (that is, when it is exposed to the air)?
2. Compare the feeding responses of the barnacle in the presence and in the absence of food. Is there a measurable difference?
3. Explain how the barnacle is adapted for filter-feeding. What special structures and functions did you observe that help the barnacle survive?

## Chapter 21 Review

*Answer the following questions on a separate sheet of paper.*

### Vocabulary

*The following list contains all the boldface terms in this chapter.*

abiotic factors, biotic factors, climax community, commensalism, ecological succession, ecology, ecosystem, food chain, food pyramid, food web, lichen, marine ecology, mutualism, nitrogen fixation, omnivore, parasitism, pioneer community, predator, prey, primary consumer, scavengers, secondary consumer, tertiary consumer, trophic level

### Fill In

*Use one of the vocabulary terms listed above to complete each sentence.*

1. A relationship in which both species benefit is called \_\_\_\_\_.
2. A \_\_\_\_\_ shows the trophic levels in a food chain.
3. The \_\_\_\_\_ is the first group of living things in an area.
4. Zooplankton would be the \_\_\_\_\_ in an ocean food chain.
5. The nonliving factors in an environment are called \_\_\_\_\_.

### Think and Write

*Use the information in this chapter to respond to these items.*

6. What is the difference between mutualism and commensalism?
7. Why are producers more abundant than consumers in a habitat?
8. Explain why a climax community is not always permanent.

### Inquiry

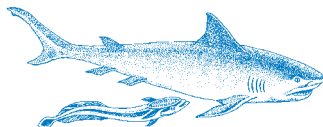
*Base your answers to questions 9 through 11 on Figure 21-7 on page 525, which shows a marine food web, and on your knowledge of marine science.*

9. In terms of numbers, which is the most abundant organism in the food web? Explain.
10. Which organism in the food web is the least numerous? Explain why.
11. How would a sudden decline in the herring population affect the food web?

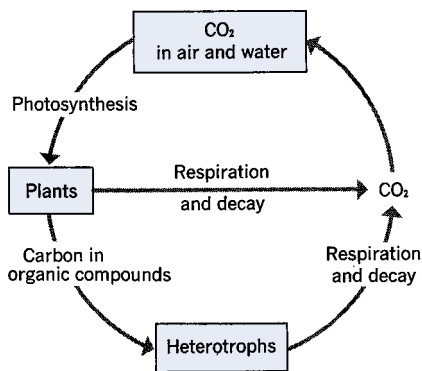
### Multiple Choice

Choose the response that best completes the sentence or answers the question.

12. Which statement is most correct about the relationship between the two fish shown here?
  - a. Both fish benefit equally.
  - b. The shark benefits and the remora is harmed.
  - c. The remora benefits and the shark is harmed.
  - d. The remora benefits and the shark is unaffected.



13. The ecological cycle shown here provides plants in the marine ecosystem with
  - a. carbon to carry out photosynthesis
  - b. phosphorus for ATP production
  - c. oxygen to carry on aerobic respiration
  - d. a source of nitrogen for protein synthesis.



14. A producer–consumer interaction in the marine ecosystem is illustrated by
  - a. bacteria feeding on detritus
  - b. sea gulls scavenging on dead clams
  - c. snails grazing on algae
  - d. a fish eating a shrimp.
15. The nitrogen cycle makes it possible for marine algae to
  - a. carry on photosynthesis
  - b. breathe
  - c. produce ATP
  - d. synthesize proteins.

16. The flow of energy in a food chain occurs as follows:  
*a.* consumer to producer to producer *b.* decomposer to producer to consumer to producer *c.* producer to consumer to decomposer to consumer *d.* producer to consumer to decomposer to producer.
17. The carbon cycle and the oxygen cycle directly involve  
*a.* consumers and decomposers *b.* producers and consumers *c.* predators and prey *d.* predators and consumers.

*Base your answers to questions 18 through 21 on the following food relationship: algae → shrimp → lobster → octopus.*

18. This sequence illustrates a *a.* food web *b.* food pyramid  
*c.* food chain *d.* food cycle.
19. The population of which organism has the highest food energy? *a.* algae *b.* shrimp *c.* lobster *d.* octopus
20. Which organism is the most numerous in its habitat?  
*a.* algae *b.* shrimp *c.* lobster *d.* octopus
21. Which organism is both predator and prey here? *a.* algae  
*b.* shrimp *c.* lobster *d.* octopus
22. The cleaning wrasse that eats parasites living on a grouper's skin provides an example of *a.* commensalism  
*b.* succession *c.* mutualism *d.* parasitism.
23. The correct sequence for plant communities on an island is  
*a.* mosses, lichens, shrubs, trees, grasses *b.* lichens, mosses, grasses, shrubs, trees *c.* grasses, mosses, lichens, trees, shrubs *d.* lichens, grasses, mosses, trees, shrubs.

### **Research/Activity**

With a team of classmates, set up a saltwater aquarium tank containing some local marine species, such as killifish, snails, seaweed, shore shrimp, and mussels. Identify the producers, consumers, and decomposers (scavengers) in the aquarium. Prepare a poster board that shows the food relationships among the different organisms. (*Remember:* Do not overstock the tank, and be sure to use proper filtration and aeration.)