- The amount of solar energy converted to chemical energy is called primary production and depends on the ecosystem. Forests and wetlands have greater primary production than deserts or open ocean. Energy supply limits length of food chains. At each level, much energy is lost to detritus and much is used in cellular respiration. Only 5–20% is passed on to the next level, supporting few tertiary or quaternary consumers.
- Chemical nutrients, such as carbon, phosphorus, and nitrogen, are recycled. Details vary but each biogeochemical cycle has (an) abiotic reservoir(s)—phosphate in rocks and soil, CO_2 and N_2 in the air. Producers assimilate nutrients and pass them on to consumers. Organisms excrete wastes and die, and detritivores and decomposers return nutrients to soil, water, or air. Deforestation, fossil fuel use, and sewage runoff can disrupt these cycles.

Review the Concepts

Work through the following exercises to review the concepts in this chapter. For additional review, refer to the activities on the Web at www.mybiology.com. The website offers a pretest that will help you plan your studies.

Exercise 1 (Modules 37.1–37.7)

The structure of a community is shaped by interactions among the populations making up the community. The most important kinds of interactions are **competition**, **predation**, **herbivory**, **parasitism**, and **mutualism**. State which of these five interactions is described in each of the examples below. Then put a + or − in each of the parentheses ( ) to indicate whether the relationship is positive or negative for each organism.

_____ 1. Sheep liver flukes ( ) feed on bile and can weaken or kill their hosts ( ). They are passed on to other sheep in the animals' droppings.

_____ 2. Grazing by introduced mountain goats ( ) has reduced the numbers of alpine wildflowers ( ) in Olympic National Park.

_____ 3. Pest control specialists have brought in a moth ( ) to eat tansy ragwort, ( ) a poisonous weed.

_____ 4. Mistletoe ( ) obtains nutrients from an oak tree ( ).

_____ 5. Mycorrhizal fungi ( ) associated with roots obtain carbohydrates from a tree, while enabling the tree ( ) to absorb water and minerals more efficiently.

_____ 6. In many parts of North America, the starling ( ) has displaced the bluebird ( ) from its nest sites.

_____ 7. A bee ( ) pollinates a tropical orchid ( ) by being tricked into "mating" with the flower; the bee uses a perfume from the flower to attract a mate.

_____ 8. The influenza virus ( ) attacks the lining of the respiratory tract and is passed from person ( ) to person by contact or airborne droplets.

_____ 9. Red-winged blackbirds ( ) arrive earlier on the breeding grounds but are forced to the edges of a marsh by larger, later-arriving yellow-headed blackbirds ( ).

_____ 10. Lions ( ) hunt large herbivorous mammals such as zebras and wildebeest ( ).

_____ 11. A tropical acacia tree ( ) spouts under the taller canopy trees ( ) and grows up toward the light.

_____ 12. The acacia ( ) is infested by ants ( ) that live in enlarged tree thorns and feed on special leaves. As the tree grows, the ants prune away leaves and branches of surrounding trees.

Exercise 2 (Modules 37.2–37.7)

Each species in a community has an ecological niche, its "role" or "job" in the community. The niche includes the sum of the organism's needs, functions, abilities, and tolerances. It is possible to describe the niche as a sort of "job description" for a species, as you might see in a classified ad. An ad that reads "Applicant will be required to travel in herd, drink through nose, and knock down trees for food" could only describe the job of an elephant!

Identify the organism whose niche is outlined in each of the following job descriptions. Some are from the text; others are not but will probably (like the elephant) be familiar to you.

_____ 1. "Must be skilled at building traps to catch flying insects. May or may not need to devour mate."

_____ 2. "Ability to build and maintain reef. Must be able to work closely with dinoflagellates."

_____ 3. "Will be traveling and working outdoors in cold weather. Must have the patience to wait long periods to catch and eat seals through hole in ice. Some swimming ability and camouflage helpful."

_____ 4. "Passionflower specialist wanted. Must be able to break down toxins."

_____ 5. "Must be able to withstand coastal storms and forest fires while maintaining species' reputation as world's tallest tree."

_____ 6. "Must live in South American rain forest, eat insects, and have poison glands and bright coloration."

_____ 7. "Will work closely with legume. Will be required to fix nitrogen in exchange for daily carbohydrate allowance."

_____ 8. "Ability to eat insects important. May be called upon to compete with orange-crowned warblers."

_____ 9. "Must be able to climb trees and eat acorns."

Exercise 3 (Modules 37.8–37.9)

The trophic structure of an ecosystem is the pattern of feeding relationships by which energy and chemicals flow through the system from trophic level to trophic level. Name the trophic level of each of the organisms in the following description of a freshwater marsh food web: producer (P), primary consumer (1C), secondary consumer (2C), tertiary consumer (3C), quaternary consumer (4C), detritivore or scavenger (S), or decomposer (D). (Note that a consumer can function on more than one level, depending on what it eats.)

Marshes and other wetlands are among the most endangered of habitats. They are productive "nurseries" for many wildlife species, but many of our wetlands have been drained for agriculture or filled for development.

The freshwater marsh food web starts with plants like cattails, arrowleaf, and various floating or submerged "water weeds" ([1]_____). They provide food for muskrats ([2]_____) and mallard ducks ([3]_____), both of which may in turn be eaten by hawks ([4]_____) or mink ([5]_____). Microscopic algae ([6]_____) make much of the food in the marsh. Small shrimplike crustaceans ([7]_____) and insect larvae ([8]_____) graze on the algae. The crustaceans and insects are eaten by ducks ([9]_____), frogs ([10]_____), and sunfish ([11]_____). A frog or sunfish might be eaten by a larger yellow perch ([12]_____), a great blue heron ([13]_____), a water snake ([14]_____), or a mink ([15]_____). The heron ([16]_____) also eats perch and snakes, and the hawk ([17]_____) will also occasionally devour a snake.

Exercise 5 (Module 37.12)

Gradual transition in the species composition of a community that occurs after a disturbance is called ecological succession, described in Module 37.12. In this exercise, first state whether each of the following represents a relatively early (E) stage in succession or a relatively late (L) stage. (Hint: Ask yourself if the community were left untouched, whether it would look the same or different in a hundred years. If it would look different, it is in an early stage—there are later stages to come.) Next, for those communities in an early stage, state whether those examples represent primary (P) or secondary (S) succession.

Early or Late?	*Primary or Secondary?*	
_____	_____	1. Lichen-covered rocks near a melting glacier in Alaska
_____	_____	2. "Old growth" conifer forest in the Pacific Northwest
_____	_____	3. A weedy vacant lot near your college
_____	_____	4. An oak-maple-beech forest in Ohio
_____	_____	5. A lava flow on the island of Hawaii
_____	_____	6. A lawn in a suburb in New Jersey
_____	_____	7. A cornfield in Virginia

Exercise 6 (Module 37.13)

Invasive species can drastically alter communities. The introduction of rabbits to Australia is a dramatic example. Dutch elm disease (Module 37.7) is another. Several other examples are described in Module 19.18.

1. What are three kinds of circumstances that allow an introduced species to spread unchecked? In other words, what kinds of controls might be relaxed in a new environment?

2. What is biological control? Why is biological control a good way to deal with introduced species?

3. Why does biological control not always work? Give three ways it can go wrong.

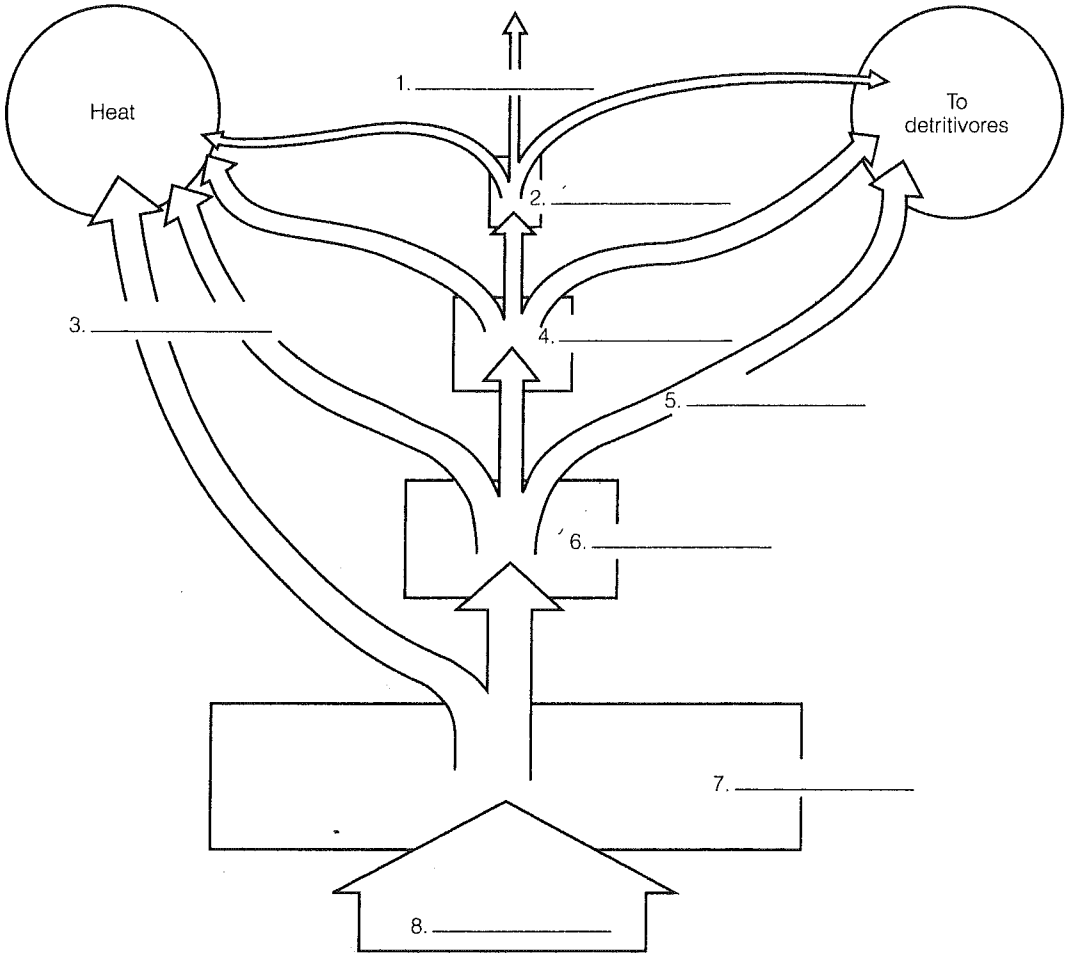
Exercise 7 (Modules 37.14–37.15)

Sunlight, moisture, and nutrient availability determine how much food the producers of an ecosystem can make—primary production. After studying the bar graph, rank the following ecosystems in terms of primary production per square meter per year (highest pp = #1, lowest pp = #8).

_____ A. Desert
_____ B. Tropical rain forest
_____ C. Cornfield
_____ D. Beech/maple forest
_____ E. Open ocean
_____ F. Estuary
_____ G. Tundra
_____ H. Kelp bed

Exercise 8 (Modules 37.15–37.17)

The flowchart on the following page illustrates the movement of energy through an ecosystem. The boxes represent the biomass of organisms at each trophic level. The arrows show the amount of energy passing through each trophic level. Energy enters the producer level as sunlight. Some of this energy is stored in molecules produced in photosynthesis. Energy enters each of the consumer trophic levels when the consumers feed on the level below. Much of the energy in the food entering any level is used to power life processes; the food is used as fuel in cellular respiration, and its energy ends up as heat. Some energy is wasted; it is lost to the detritus food web in the form of dead leaves or droppings. A small portion of the energy is stored in tissue when organisms grow or reproduce; this production—roughly 5–20% of energy intake at any trophic level—is the only energy available to the next level. Label and color the trophic levels on the diagram: **producers** (green), **primary consumers** (orange), **secondary consumers** (blue), and **tertiary consumers** (purple). Label and color the pattern of energy flow: **sunlight** (yellow), **production energy** (red), **energy used in cellular respiration** (pink), and **energy in wastes** (brown). (Note: Can you see from this diagram why quaternary consumers are quite rare?)



Exercise 9 (Modules 37.1–37.23)

The biosphere receives a constant supply of energy from the sun, uses this energy for a while, then loses it to space as heat. Unlike energy, the chemicals necessary for life are present on Earth in fixed amounts, and these chemicals are used over and over. These chemicals, such as carbon, nitrogen, and phosphorus, occur in various forms and are changed from one form to another by various physical and chemical processes. The story below traces a nitrogen atom as it moves through the various reservoirs and processes of the nitrogen cycle. Fill in the blanks as you follow its journey.

The nitrogen atom, N, had been in the atmosphere for more than two years. It was paired with another identical nitrogen atom, forming a molecule of [1]_____ gas, which makes up about 80% of the air. This is by far the largest [2]_____ reservoir of nitrogen. During its time in the atmosphere, N had circled Earth several times, from the skies over the Philippines, to Africa, to the Antarctic, to South America, and now over a sand dune in North Carolina. There it was captured by [3]_____ in a nodule on the root of a legume called a beach pea. There N was split away from its partner and combined with hydrogen atoms, eventually ending

up in an amino group in a protein molecule built by the plant. This N entered (or reentered!) the [4]_____ reservoir of this global [5]_____ cycle. The protein was stored in one of the peas, which ripened, dried, and fell on the ground, and it was eaten by a mouse. The amino acid from the pea was incorporated into a [6]_____ molecule in a leg muscle of the mouse. On a moonlit night a month or so later, a great horned owl caught the mouse, and N became part of a protein molecule in one of the owl's feathers. And there it remained until the following spring.

In the spring, as every spring, the owl molted some of its feathers. The small feather containing N ended up in the litter under a pine tree. [7]_____ in the soil broke down the feather over a period of several months, and N was eventually released into the soil, in the form of [8]_____, NH_4^+. Other bacteria, called [9]_____ bacteria, then attached N to three oxygen atoms, forming [10]_____, which was taken up by a huckleberry bush and used to build another protein. The huckleberry was eaten by a cardinal, which broke down the protein and eventually excreted N in the uric acid in its droppings. Decomposers in the forest soil changed this waste product to [11]_____, which nitrifying bacteria quickly converted into [12]_____.

When the patch of forest was cut for lumber, most of the nitrate ions in the soil were washed downhill. A flood deposited the nitrate ion containing N in the soil of a flat river valley. N was soon absorbed by the roots of a buttercup plant—a process called [13]_____. The buttercup used N to make an [14]_____, which was used to build a protein molecule, which ended up in a pollen grain. A beetle collected some of this pollen, and soon N was part of the insect's body. The beetle flew into a bog and landed on the leaf of a Venus flytrap, an insect-eating plant. The leaf snapped shut, and the beetle was slowly digested; the plant used N to make its own proteins.

About a year later, the rotting trunk of a dead tree toppled into the swamp and buried the Venus flytrap. As the plant decomposed, bacteria again incorporated N into ammonium and then nitrate. But this time, in the low-oxygen conditions of the mud, [15]_____ bacteria were able to break down the nitrate ions, releasing N to the air as part of an N_2 molecule. The wind swept the molecule out over the ocean, where . . .

You might find it informative and fun to continue the story from here. You might also find it helpful to make up similar stories for a carbon atom or a phosphorus atom. This is a good review to do in a study group.

Test Your Knowledge

Multiple Choice

1. All of the populations of organisms in a particular area make up
   a. a food chain.
   b. a biogeochemical cycle.
   c. an ecosystem.
   d. a niche.
   e. a community.

2. When you eat an apple, you are a
   a. primary consumer.
   b. secondary producer.
   c. producer.
   d. secondary consumer.
   e. tertiary consumer.

3. An organism's "trophic level" refers to
   a. the rate at which it uses energy.
   b. where it lives.
   c. what it eats.
   d. whether it is early or late in ecological succession.
   e. the intensity of its competition with other species.

4. The relationship between species A and species B is described as mutualism. This means that
   a. both species suffer.
   b. one species benefits and the other species suffers.
   c. both species benefit.
   d. one species benefits and the other species is unaffected.
   e. any of the above is possible in mutualism.

5. Most plants get nitrogen from
   a. nitrates in the soil.
   b. N_2 gas in the air.
   c. proteins.
   d. ammonium in the soil.
   e. rainfall.

6. The energy for nearly every organism in nearly every ecosystem ultimately comes from
   a. minerals in the soil.
   b. the sun.
   c. food.
   d. respiration.
   e. decomposition.

7. Why is a diagram of energy flow from trophic level to trophic level shaped like a pyramid?
   a. Organisms at each level store most of the energy and pass little on.
   b. There are more producers than primary consumers, and so on.
   c. Organisms eventually die as they get older.
   d. Most energy at each level is lost, leaving little for the next.
   e. There are always fewer secondary consumers than primary consumers, and so on.

8. The main decomposers in an ecosystem are
   a. plants and animals.
   b. bacteria and viruses.
   c. fungi and bacteria.
   d. bacteria and plants.
   e. plants and fungi.

9. In a forest, bacteria are especially important in
   a. photosynthesis.
   b. the nitrogen cycle.
   c. ecological succession.
   d. the phosphorus cycle.
   e. recycling of energy.

10. The biggest difference between the flow of energy and the flow of chemical nutrients in an ecosystem is that
    a. the amount of energy is much greater than the amount of nutrients.
    b. energy is recycled, but nutrients are not.
    c. organisms always need nutrients, but they don't always need energy.
    d. nutrients are recycled, but energy is not.
    e. organisms always need energy, but they don't always need nutrients.

11. An animal's niche is
    a. the number of individuals of the species the environment will support.
    b. the same as its habitat.
    c. the way the animal fits into its community and environment.
    d. the specific place in the habitat where the animal lives.
    e. its position in the food chain.

12. Which of the following ranks three ecosystems, from highest to lowest, in terms of primary production per square meter?
    a. open ocean—temperate grassland—desert
    b. cultivated land—estuary—deciduous forest
    c. tropical rain forest—cultivated land—coral reef
    d. cultivated land—tropical rain forest—temperate grassland
    e. coral reef—deciduous forest—open ocean

13. Gobis (fish) that eat hippo dung in Mzima Springs are best described as
    a. primary consumers.
    b. decomposers.
    c. secondary consumers.
    d. herbivores.
    e. detritivores.

14. Over time, a barren sand dune is covered by shrubs and finally a forest. This process is best described as
    a. primary succession.
    b. coevolution.
    c. secondary succession.
    d. herbivory.
    e. a biogeochemical cycle.

Essay

1. Explain in ecological terms why a given area of farmland can support more people if they eat plants rather than meat.

2. What is decomposition? What are the two major kinds of decomposers in most ecosystems, and how is their role important to the ecosystem?

3. Describe an example of coevolution between predator and prey. Are there ecological relationships other than predator/prey interactions that are shaped by coevolution between two species? Give an example.

4. State whether each of the following is a producer, primary consumer, secondary (or higher) consumer, or detritivore: squirrel, oak tree, mosquito, great white shark, moose, cheetah, mushroom, spider, phytoplankton, grass, and vulture.

5. Trace a carbon atom through the carbon cycle. In what chemical form is carbon in the air? How does a carbon atom enter the food chain? In what chemical form might the carbon atom be obtained by a consumer? What chemical process would put the carbon atom back into the atmosphere?

6. Agricultural ecosystems—cornfields or pear orchards, for example—have low species diversity. What are some potential negative consequences? How might these problems be reduced without harm to the environment?

7. Why can the productivity of an ecosystem be limited by a shortage of phosphorus or nitrogen, but seldom by a shortage of carbon? Briefly explain in terms of cycles.

Apply the Concepts

Multiple Choice

1. A lichen is actually composed of two organisms—a fungus and an alga. They depend on each other for survival. The most specific term that describes their relationship is
    a. parasitism.
    b. competition.
    c. herbivory.
    d. symbiosis.
    e. mutualism.

2. Which of the following describes mimicry?
    a. An insect's bright colors warn a predator that it tastes bad.
    b. The mottled pattern on a fish looks like dead leaves on the bottom of a pond.
    c. Two species of mice live in the same area and eat the same kinds of seeds.
    d. A harmless frog resembles a poisonous frog.
    e. Both kangaroo rats and jackrabbits hop erratically when escaping from predators.

3. When goats were introduced to an island off the California coast, the goats lived in the same areas and ate the same plants as the native deer. The deer population dwindled, and the deer finally disappeared. This is an example of
    a. herbivory.
    b. succession.
    c. a food chain.
    d. coevolution.
    e. competition.

4. Suppose you wanted to establish a self-sustaining ecosystem by sealing some sterilized soil, water, and air in a glass container with a few organisms. You would be most likely to succeed with which of the following?
    a. aphids, bacteria, and spiders
    b. bacteria and ants
    c. clover, bacteria, and grasshoppers
    d. beetles, fungi, and bacteria
    e. spiders, grasshoppers, and grass

5. After clear-cutting, timber companies cannot afford to wait for the long process of _____ to occur naturally; they usually replant trees right away.
    a. mutualism
    b. succession
    c. coevolution
    d. decomposition
    e. herbivory