Species Interactions and Community Ecology

Chapter Objectives

This chapter will help students:

- Compare and contrast the major types of species interactions
- Characterize feeding relationships and energy flow, using them to construct trophic levels and food webs
- Distinguish characteristics of a keystone species
- Characterize succession, community change, and the debate over the nature of communities
- Perceive and predict the potential impacts of invasive species in communities
- Explain the goals and the methods of restoration ecology
- Describe and illustrate the terrestrial biomes of the world

Lecture Outline

I. Central Case: Black and White, and Spread All Over: Zebra Mussels Invade the Great Lakes

   A. The pollution-fouled waters of Lake Erie and the other Great Lakes shared by Canada and the United States became gradually cleaner in the years following the Clean Water Act of 1970.

   B. Then the zebra mussel, a native to western Asia and eastern Europe, arrived by accident in the ballast water of ships.

   C. By 2010, they had colonized waters in 30 U.S states.

   D. The zebra mussels’ larval stage is well adapted for long-distance dispersal, and it has encountered none of the predators, competitors, and parasites that evolved to limit its population growth in the Old World.
E. Zebra mussels can clog up water intake pipes, damage boat engines, degrade docks, foul fishing gear, and sink buoys that ships use for navigation.

F. Zebra mussels also have severe impacts on the ecological systems they invade. Among the most significant impacts, is their ability to take large quantities of food (phytoplankton) needed by native mollusks for food.

G. Phytoplankton is the foundation of the Great Lakes food web, so its depletion is bad news for zooplankton, the tiny aquatic animals and protists that eat phytoplankton—and for the fish that eat both.

H. By filter feeding, zebra mussels clear the water, allowing the community’s nutrient balance to shift to the bottom, possibly benefitting species feeding there.

I. Most recently, the zebra mussel is being displaced by the quagga mussel. Scientists do not yet understand the complex interactions driving the change. The quagga has a larger niche than any native mussels and even the zebra mussel.

II. Species Interactions

A. **Competition** can occur when resources are limited.

1. Competitive interactions can take place among members of the same species (**intraspecific competition**), or among members of two or more different species (**interspecific competition**).

2. A competitive relationship is represented in Table 4.1 as a /-/- interaction.

3. **Competitive exclusion** occurs when one species excludes the other from resource use entirely.

4. Competing species that live side-by-side at a certain ratio of population sizes may reach a stable equilibrium point—**species coexistence**.

5. Coexisting species that use the same resources tend to minimize competition by using only a portion of the total array of resources—their niche, or ecological role in the community—that they are capable of using.
   a. The full niche of a species is called its **fundamental niche**.
   b. An individual that plays only part of its role because of competition or other species interactions is said to be displaying a **realized niche**.

6. Over time, competing species may evolve to use slightly different resources or to use their shared resources in different ways; this is **resource partitioning**.
   a. Because species limit their resource use, over time, **character displacement** may occur as they evolve physical characteristics that reflect their reliance on a particular portion of the resource.
B. Several types of interactions are *exploitative*.

1. Exploitation occurs when one member of an interaction exploits another for its own gain.
2. An exploitative interaction is represented in Table 4.1 as a +/- relationship.
3. Predators kill and consume prey.
   a. **Predation** is the process by which an individual of one species, a predator, hunts, captures, kills, and consumes an individual of another species, its *prey*.
   b. Predation can sometimes drive population dynamics, causing cycles in population sizes.
   c. Predation also has evolutionary ramifications: More adept predators will leave more and healthier offspring, leading to the evolution of adaptations that make them better hunters. The same selective pressure acts on prey species that evolve defenses against being eaten.
4. Parasites exploit living hosts.
   a. **Parasitism** is a relationship in which one organism, the *parasite*, depends on another, the *host*, for nourishment or some other benefit while simultaneously doing the host harm.
   b. Parasitism usually does not result in an organism’s immediate death.
   c. Many parasites live in close contact with their hosts, such as disease pathogens, tapeworms, ticks, and lamprey.
   d. Other types of parasites are free-living and come into contact with their hosts only infrequently (e.g., nest parasites such as cuckoos and cowbirds).
   e. Some parasites cause little harm, but others may kill their hosts to survive, called *parasitoids*.
   f. Hosts and parasites can become locked in a duel of escalating adaptations called the evolutionary arms race, resulting in *coevolution*.
5. Herbivores exploit plants.
   a. **Herbivory** occurs when animals feed on the tissues of plants.
   b. Herbivory does not kill the plant, but can affect growth and reproduction.
C. Mutualists help one another.

1. **Mutualism** is a relationship in which two or more species benefit from interacting with one another.
2. Many mutualistic relationships—like many parasitic relationships—occur between organisms that live in close physical contact; this is called *symbiosis*.
a. Free-living organisms such as bees and flowers also engage in mutualism in the process of **pollination**.

D. Some interactions have no effect on some participants.
   1. **Amensalism** is a relationship in which one organism is harmed and the other is unaffected.
   2. **Commensalism** occurs when one organism benefits and the other is unaffected.

III. **Ecological Communities**
   A. Energy passes among trophic levels.
      1. As organisms feed on one another, energy moves through the community, from one rank in the feeding hierarchy, or **trophic level**, to another.
         a. **Producers**, or **autotrophs** ("self-feeders"), comprise the first trophic level.
             i. Producers include terrestrial green plants, cyanobacteria, and algae, and all of them capture solar energy and use photosynthesis to produce sugars.
             ii. The chemosynthetic bacteria of hot springs and deep-sea hydrothermal vents use geothermal energy in a similar way to produce food.
         b. The second level consists of organisms that consume producers (e.g., deer and grasshoppers) are known as **primary consumers**.
            i. Most of them consume plants and are called herbivores.
            ii. Examples include deer and grasshoppers.
         c. The third level consists of **secondary consumers**, which prey on primary consumers.
            i. Wolves preying on deer are an example of secondary consumers.
         d. Predators that feed at higher trophic levels are known as **tertiary consumers**
            i. An example of this is hawks that eat rodents that have eaten grasshoppers.
         e. Secondary and tertiary consumers are carnivores because they eat animals.
         f. Animals that eat both plant and animal food are omnivores.
         g. Detritivores and decomposers consume nonliving organic matter.
   B. Energy, biomass, and numbers decrease at higher trophic levels.
1. At each trophic level, most of the energy that organisms use is lost through respiration.

2. The first trophic level (producers) contains a large amount of energy, while the second (primary consumers) contains less energy—only that amount gained from consuming producers.

3. The third trophic level (secondary consumers) contains still less energy, and higher trophic levels (tertiary consumers) contain the least.

4. A general rule of thumb is that each trophic level contains just 10% of the energy of the trophic level below it, although the actual proportion can vary greatly.

5. This pattern can be visualized as a pyramid, and also tends to hold for the numbers of organisms at each trophic level, with fewer organisms existing at higher trophic levels than at lower trophic levels.

6. This same pyramid-like relationship also often holds true for biomass: the collective mass of living matter in a given place and time.

7. Humans can decrease their ecological footprint by eating lower on the pyramid—choosing vegetarianism or reducing meat consumption that takes more energy from the trophic pyramid than a plant-centered diet would.

C. Food webs show feeding relationships and energy flow.

1. As energy is transferred from species on lower trophic levels to species on higher trophic levels, it is said to pass up a food chain, a linear series of feeding relationships.

2. A food web is a visual map of energy flow, showing the many paths by which energy passes among organisms as they consume one another.

D. Some organisms play bigger roles in communities than others.

1. A keystone species is a species that has a particularly strong or far-reaching impact.
   a. Large-bodied secondary or tertiary consumers are often considered keystone species.
   b. Predators at high trophic levels can promote populations of organisms at low trophic levels by keeping species at intermediate trophic levels in check. This is called the trophic cascade.
   c. Some species attain keystone species status not through what they eat, but by physically modifying the environment.

E. Communities respond to disturbance in different ways.

1. Human activities are among the major forces of disturbance in ecological communities worldwide.
2. A community that resists change and remains stable despite disturbance is said to show **resistance** to the disturbance.

3. Alternatively, a community may show **resilience**, meaning that it changes in response to disturbance but later returns to its original state.

4. A community may be modified by disturbance permanently and may never return to its original state.

F. **Succession follows severe disturbance.**

1. If a disturbance is severe enough to eliminate all or most of the species in a community, the affected site will undergo a somewhat predictable series of changes that ecologists call **succession**.
   a. **Primary succession** follows a disturbance so severe that no vegetation or soil life remains from the community that previously occupied the site. In primary succession, a biotic community is built essentially from scratch.
   b. **Secondary succession** begins when a disturbance dramatically alters an existing community but does not destroy all living things or all organic matter in the soil.
   c. At terrestrial sites, primary succession takes place after a bare expanse of rock, sand, or sediment becomes newly exposed. Species that arrive first and colonize the new substrate are referred to as **pioneer species**.
      i. Pioneer species, such as lichens, are the first to arrive.
      ii. Lichens secrete acid, starting the process of soil formation.
      iii. New, larger organisms arrive, establish themselves, and pave the way for more new species, where eventually a climax community becomes established.

2. In the traditional view of succession, the transitions between stages of succession eventually lead to a climax community, which remains in place with little modification until some disturbance restarts succession.

G. **Communities may undergo shifts.**

1. Today, ecologists recognize that the dynamics of community change are far more variable and less predictable than originally thought.

2. In addition, climax communities are not determined solely by climate, but rather may vary with soil conditions and other factors from one time or place to another.

3. Moreover, once a community is disturbed and changes are set in motion, there is no guarantee that the community will ever return to its original state.

4. A **phase shift or regime shift** is where the overall character of the community fundamentally changes.
H. How cohesive are communities?
1. Frederick Clements promoted the view that communities are cohesive entities whose members remain associated over time and space.
2. Henry Gleason maintained that each species responds independently to its own limiting factors, and that species can join or leave communities without greatly altering their composition.
3. Today, ecologists side largely with Gleason, although they see validity in aspects of both ideas.

I. Invasive species pose new threats to community stability.
1. An invasive species is a non-native organism that arrives in a community from elsewhere, spreads, and becomes dominant, with the potential to substantially alter a community.
2. Introduced species may become invasive when limiting factors that regulate their population growth are absent.
3. In most cases, ecologists view invasive species as having overall negative impacts on ecosystems.
4. In rare cases, non-native species like the honeybee provide important economic benefits to agriculture and ornamental crops.
5. In case after case, managers are finding that controlling and eradicating invasive species are so difficult and expensive that preventive measures represent a much better investment.

J. Altered communities can be restored.
1. The practice of ecological restoration is informed by the science of restoration ecology, with research into the history of an area as well as an understanding of its “presettlement” condition.
2. Efforts to restore areas to a more pristine habitat are known as ecological restoration.
3. Ecological restoration is often time consuming and expensive. A restored system may not match the diversity of the original landscape. It is better to protect natural landscapes from degradation.

IV. Earth’s Biomes
A. A biome is a major regional complex of similar communities—a large ecological unit recognized primarily by its dominant plant type and vegetation structure.
1. The world contains a number of biomes, each covering large, continuous geographic areas.

B. Climate influences the locations of biomes.
1. A biome depends on a variety of abiotic factors—including temperature, precipitation, atmospheric circulation, and soil characteristics.

2. Scientists often use climate diagrams, or climatographs, to depict annual patterns and monthly averages of temperature and precipitation.

C. Aquatic and coastal systems also show biome-like patterns.

1. One might consider the shallows along the world’s coastlines to represent one aquatic system, the continental shelves another, and the open ocean, deep sea, coral reefs, and kelp forests as still other distinct sets of communities.

2. Many coastal systems—such as salt marshes, rocky intertidal communities, mangrove forests and estuaries—share both terrestrial and aquatic components.

3. Freshwater systems such as those in the Great Lakes are widely distributed throughout the world.

D. We can divide the world into roughly 10 terrestrial biomes.

1. Temperate deciduous forest is found in eastern North America and is characterized by broadleaf trees that lose their leaves in the fall.

2. Moving westward from the Great Lakes, we find temperate grasslands that were once widespread but have now been mostly converted to agricultural land.

3. Temperate rainforest is found in the Pacific Northwest and is a forest type known for its high biodiversity and potential to produce large volumes of commercially important products.

4. Tropical rainforest is found in regions near the equator, and is characterized by high rainfall year-round, uniformly warm temperatures, high biodiversity, and lush vegetation.

5. Tropical areas that are warm year-round but where rainfall is lower overall and highly seasonal give rise to tropical dry forests, or tropical deciduous forests.

6. Dry tropical areas across large stretches of Africa, South America, India, and Australia are savannas—regions of grasslands interspersed with clusters of trees.

7. Desert is the driest biome on Earth, and much of the rainfall occurs during isolated storms. Deserts are not always hot, but they have low humidity and relatively little vegetation to insulate them. Temperatures, therefore, may vary widely from day to night and across seasons.

8. Tundra is nearly as dry as desert, but is located in cold regions at very high latitudes along the northern edges of Russia, Canada, and Scandinavia. Little daylight in winter and lengthy, cool days in summer
result in a landscape of lichens and low, scrubby vegetation without trees.

9. The northern coniferous forest, or boreal forest, often called taiga, develops in cooler, drier regions than temperate rainforests. Taigas stretch in a broad band across much of Canada, Alaska, Russia, and Scandinavia.

10. Chaparral is found in areas of Mediterranean climate, and consists of densely thicketed evergreen shrubs.

E. Altitude creates patterns analogous to latitude.

1. Not only does temperature drop at progressively higher altitudes, atmospheric pressure (and oxygen) declines too, while ultraviolet radiation increases.

2. Mountains can alter local climates in other ways, such as through the rainshadow effect, creating a relatively arid region in the rainshadow region.

V. Conclusion

A. The natural world is so complex that we can visualize it in many ways and at various scales.

B. Dividing the world’s communities into major types, or biomes, is informative at the broadest geographic scales.

C. Understanding how communities function at more local scales requires an understanding of how species interact with one another.

D. Increasingly, humans are altering communities.

Key Terms

- amenalism
- biomass
- biome
- boreal forest
- chaparral
- character displacement
- climatographs
- coevolution
- commensalism
- community
- competition
- competitive exclusion
- desert
- ecological restoration
- food chain
- food web
- fundamental niche
- herbivory
- interspecific competition
- intraspecific competition
- invasive species
- keystone species
- mutualism
- parasitism
- permafrost
- phytoplankton
pioneer species  succession
pollination  symbiosis
predation  temperate deciduous forest
primary succession  temperate grasslands
realized niche  temperate rainforest
resilience  trophic cascade
resistance  trophic level
resource partitioning  tropical dry forest
restoration ecology  tropical rainforest
savanna  tundra
secondary succession  zooplankton
species coexistence

Teaching Tips
1. Have students research a local environment and create a graphic of a food web in that environment.

2. Consider purchasing a program, such as EcoBeaker from SimBiotic Software (www.ecobeaker.com), for use as homework or in a laboratory setting. You can choose how many modules you want to use (there are 20 modules available in EcoBeaker and six modules in EvoBeaker), and pay for those modules on an annual basis. They currently require a minimum order of $500 per year. The fees are generally based on the number of students that will use the module and the number of modules you want to use, in addition to other factors. “Isle Royale” is about the moose and wolf populations on Isle Royale in Lake Superior, and explores predator-prey cycles, logistic and exponential population growth, carrying capacity, and energy flow. “Keystone Predator” re-creates Paine’s famous sea star Pisaster experiments in the Pacific Northwest, exploring food webs, community structure, competition, and keystone species. They will send you a free sample package of demonstration modules upon request.

3. Ask your students to think of examples of species interactions that are not discussed in the textbook. You may need to guide them through a classic example, such as the commensalism between clownfish and anemones, or the mutualism between oxpeckers and the black rhinoceros.

4. Species in danger of extinction are protected under the Endangered Species Act of 1973. The U.S. Fish and Wildlife Service is the agency that protects listed terrestrial and freshwater species. Information about endangered and threatened species can be found on the U.S.F.W.S. Endangered Species Program website at http://endangered.fws.gov. Using this website, students should be able to find information about local species that are on the list. Have each student choose an organism and write a short paper about the history, current status, and conservation plan, including information from recent news releases.
5. Rather than teaching about biomes yourself, have your students do a biomes project to learn from each other. Separate the students into small groups and have them choose a biome or a special subset of a biome to study, such as wetlands divided into swamps, bogs, and estuaries; deserts divided into hot deserts and cool deserts; or ocean shorelines divided into sandy shores, rocky (tidepool) shores, and barrier islands. The groups can then create a poster or a short PowerPoint presentation on their chosen topic. This would need to include:

- World distribution of the biome (include a map)
- Major characteristics of the biome—elevation, geology, climate, temperature, rainfall, seasonality, and winds
- Several representative animals and plants
- Indigenous peoples
- Two anthropogenic problems that threaten the biome
- Something that is being done to address one of the problems, as well as its results
- A table, graph, or chart relating to the biome
- A listing of resources that were used in researching the project

Grading should be based on the satisfactory gathering of the above information, as well as on an oral presentation if time permits. The oral presentation should include:

- An introduction with a question, humor, or attention-getting fact
- Good transitions between presenters and topics within the presentation
- Presentation of the material without notes and using proper pronunciation
- Loud, clear voices and good presentation appearance
- Good closure, with a summary, a final idea, humor, a suggestion for action, or other appropriate ending

Additional Resources

Websites

1. *The World’s Biomes*, University of California Museum of Paleontology
   (www.ucmp.berkeley.edu/glossary/gloss5/biome)
   This resource describes the major biomes: aquatic, deserts, grasslands, forests, and tundra.

2. *Invasivespeciesinfo.gov*, National Agricultural Library, United States Department of Agriculture (www.invasivespeciesinfo.gov)
This website is a gateway to federal and state invasive species programs, activities, databases, and links to primary documents and related websites.


This Web-based audio news report addresses the theory that orca are causing severe decreases in the Alaskan sea otter population.


This is the home page for the Society for Ecological Restoration International, with links to past and existing restoration projects and primary documentation.

5. The Natural Resources Defense Council features a Web-based system called *Biogems* (www.nrdc.org/biogems)

In this search mode, students can learn about the unique natural “gems” highlighted based on their biodiversity, scenic beauty, significance as habitats for endangered species, or whether they are in danger of being developed.

**Audiovisual Materials**


   This is a five-part program that examines biomes as interconnected parts of a global ecosystem. It is available in DVD, VHS, and digital-on-demand formats.


   This program illustrates the alarming environmental and commercial impact of non-native invasive plants. It is available in DVD, VHS, and digital-on-demand formats.


   This program chronicles the decline of the prairie dog—a keystone species—in the American West.

4. *Interdependence of Life*, 2005, a Cambridge Educational Production, distributed by Films for the Humanities and Sciences (www.films.com)

   This program examines the world’s ecosystems and explains their flow of energy and cycling of matter.

This program looks at how relationships between living things have promoted the diversity and splendor of life as it exists on Earth today.


This is a CD-ROM program with video clips of E. O. Wilson, Harvard University’s “Father of Biodiversity,” and author of “The Biophilia Hypothesis,” plus interactive exercises and maps. (www.islandpress.org)

**Weighing the Issues: Facts to Consider**

**The Footprints of Our Diets**

**Facts to consider:** The student should consider that energy is lost as it moves up a food web or food chain (from producers to tertiary consumers). Eating producers and primary consumers involves less energy loss through the food web or chain than does eating secondary and tertiary consumers (as fewer energy conversions are involved). Also, reducing animal products inevitably reduces one’s ecological footprint, as you aren’t eating the energy from the plants through an intermediary (cow, pig, chicken, etc.). Encourage students to track the amount of meat, milk, eggs, or other animal products for a day, several days, or a week to get an accurate estimate of their consumption. Then, ask them honestly if they would be willing to eliminate even one animal product meal a year in favor of a better ecological footprint.

**Are Invasive Species All Bad?**

**Facts to consider:** A community is a group of populations that interact in specific ways due to coevolution. When an invasive species moves in, these relationships are disrupted. Because non-native species are usually better competitors for resources due to a lack of factors limiting their population growth, they can cause population reductions and even the extinction of native species that use the same niche as the invader. The alien species can also have a huge impact on the entire food web of a community if it is a producer or primary consumer, because it decreases the food resources for native organisms higher in the food web. This situation is a major problem for any community, at least in the short term. In the long term (over hundreds or thousands of years), small changes in the local environment would allow for a slower advance of an invasive species, permitting native species to evolve and coexist with the invader and turning the non-native species into a native one. This is how succession occurs. Human intervention brings in a very large number of invasive species at a very fast rate, which can stop the process of evolution. A personal response is required to address ethical standards for accepting or rejecting a non-native species in any community.
Restoring “Natural” Communities

Facts to consider: The definition of “natural” will vary among students. The text refers to “historical conditions of ecological communities . . . before our industrialized civilization altered them.” However, the question of when “presettlement conditions” occurred is a matter of debate. In considering the specific scenario addressed in the question, students should consider historical data that may indicate changes in climatic conditions, and whether or not it is feasible to reintroduce species that used to live in the restoration area. Have the climate and environmental conditions changed too much to allow the reintroduced species to thrive? Do the species that were a major part of the historical community still exist? The farther back in time ecologists consider presettlement conditions for a community, the more these two questions will affect the restoration effort.

The Science behind the Stories: 
Thinking Like a Scientist

Determining Zebra Mussels’ Impacts on Fish Communities

Observation: When zebra mussels first invaded the Great Lakes, people feared that fish populations would decrease as the mussels consumed large quantities of the phytoplankton and zooplankton needed by the fish as food. However, after 15 years there is no solid evidence that fish populations have been harmed. Research conducted by David Strayer of the Institute of Ecosystem Studies and Kathryn Hattala and Andrew Kahnle of the New York State Department of Environmental Conservation found that while phytoplankton, zooplankton, and open-water invertebrate populations declined by up to 70%, benthic invertebrates in shallow water had increased notably.

Hypothesis: Introduction of the zebra mussels will harm open-water fish populations, but will benefit nearshore feeding fish. Larvae and juveniles of open-water fish species will decrease in number and growth rate, and fish populations will shift away from zebra mussel populations to the saltier water downriver. Larvae and juveniles of littoral fish species will increase in population and growth rate, and fish populations will shift upriver toward zebra mussel populations.

Study: Strayer, Hattala, and Kahnle examined three types of fish surveys that were taken over 26 years and included fish population information prior to and after 1991, when zebra mussels were first introduced to the Great Lakes.

Results: All the data analyzed supported the researchers’ hypotheses. On a larger scale, the study confirmed the hypothesis by correlating fish communities and changes in food resources. However, correlation does not prove causation, and that the cause of the changes in fish population size, growth rate, and location is not clearly shown by this study.
Otters, Urchins, Kelp, and a Whale of a Chain Reaction

Observation: In the 1990s, sea otter populations decreased dramatically off Alaska and the Aleutian Islands. Studies by a team led by James Estes of the University of California at Santa Cruz found no decrease in fertility rates or migration to other locations, leading researchers to believe that increased mortality was the cause for the population decrease. Then, in 1991, Estes’ team observed a killer whale (orca) killing and eating a sea otter. Sea otter kills by killer whales were observed nine more times in the following years.

Hypothesis: Although an individual sea otter is a low-grade food item for killer whales, killer whales were responsible for the sea otter population decline off Alaska and the Aleutian Islands.

Study: Estes and his colleagues statistically analyzed past data and found that orca attack rates on sea otters were lower prior to 1991. Two different groups of otters were compared—one population vulnerable to orca attack and one population protected from orca attack. There was no migration between populations. Data analysis showed that the vulnerable otter population decreased 76% in four years while the protected population remained stable during that time. Finally, the researchers examined otter natality and mortality rates and population age structure to estimate the number of attacks needed to decrease otter populations. The estimate of orca attacks derived from these data matched the actual, observed number of attacks.

Results: The data clearly showed that orcas were responsible for sea otter population declines in Alaskan ocean waters.

Question: Why did orcas start attacking and eating sea otters?

Hypothesis: Normal food items for orcas were scarce.

Study: Estes and his colleagues examined population data for different orca prey. They found that sea otter population declines were preceded by shrinking harbor seal populations in the late 1970s and the 1980s, decreasing sea lion populations in the 1980s, and diminishing fur seal populations in the 1970s. It was found that prior to these population reductions, the great whale populations were dwindling due to industrial whaling by countries such as Japan and Russia. Great whale populations dropped by 99% between 1965 and 1973 in the northern Pacific.

Result: Based on these data, Estes and his colleagues proposed that as the historic prey of the orcas—the great whales—became extremely scarce due to industrial whaling, the orcas began switching their main food sources to smaller and less-favorable food sources. As the population of larger prey species became exhausted, the orcas continued down the size continuum to sea otters.
Answers to End-of-Chapter Questions

Testing Your Comprehension

1. Both interspecific and intraspecific competition can restrict the ecological role played by an individual, leaving it to fill just a portion of its full potential role, the so-called fundamental niche. This more limited role is the so-called realized niche. Species adapt to competition by evolving to use different resources, or to use shared resources in different ways.

2. Predation is the relationship in which one organism, a predator, consumes another, its prey. Parasitism is a relationship in which one organism, the parasite, depends on another, the host, for nourishment or some other benefit while simultaneously harming the host (but generally not killing it). Herbivory is the consumption of a plant or a portion of a plant by an animal, the herbivore.

3. Fungi and plant roots that form associations called mycorrhizae are symbiotic mutualisms. Bees pollinating plants while ingesting nectar exemplify a non-symbiotic mutualism. Many agriculturally important plant species require insect pollination. Moreover, each one of us depends on symbiotic bacteria in our digestive tracts to continue living.

4. A trophic level is a rank in the feeding hierarchy of a community, with plants and/or chemoautotrophic producers occupying the first trophic level, and various consumers occupying the second trophic level. If this list of who eats whom is extended, you have a food chain. In reality, it is common for one species to consume and be consumed by multiple species, resulting in a network of feeding relationships called a food web.

5. A species might be considered a keystone species if its removal from the ecosystem causes pervasive ripple effects throughout the food web. Removal of predators at high trophic levels can result in increased prey abundance, which may cause decreased abundance of their food as they overgraze. Other species that have major effects because they physically modify the environment shared by community members (as beavers and their dams do) are more often considered “ecosystem engineers.”

6. Primary succession involves the establishment of an ecological community in an area that has never before been colonized by life (for example, on fresh lava flows or land that has been uncovered by melting glaciers). Secondary succession begins with the recolonization of an area following a significant disturbance, such as the regrowth of natural vegetation on an abandoned farm field. In each case, the community alters the physical environment over time and responds to that changing environment.

7. Changes to the Great Lakes include increased numbers of zebra mussels, decreased smaller zooplankton and plankton-eating fish, decreased numbers of native mollusks that compete with zebra mussels, increased cyanobacterial populations, increased numbers of benthic organisms that make use of zebra
mussel waste nutrients, and increased food for organisms that eat zebra mussels (ducks, crayfish, muskrats, etc.). (Figure 4.16a)

8. Restoration ecology is the pursuit of researching and restoring the historical conditions of ecological communities as they existed before industrialized civilization. This is important, as it can restore the functionality of a system, and/or reduce the human impact on an environment.

9. Terrestrial biomes’ distributions are most strongly influenced by climate, which can be summarized in a climatograph of average monthly temperature and precipitation. Water temperature, depth, salinity, dissolved nutrients, wave action, currents, and type of substrate shape aquatic ecosystems’ distributions.

10. See Figure 4.23b and Figure 4.26b. These diagrams indicate the range and timing of temperature and moisture stresses likely to be faced by organisms in those biomes.

## Calculating Ecological Footprints

<table>
<thead>
<tr>
<th>Group of organism</th>
<th>Percentage of total introduced</th>
<th>Number of species introduced</th>
<th>Percentage of total annual costs</th>
<th>Annual economic costs</th>
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<td>Plants</td>
<td>50.0</td>
<td>25,000</td>
<td>27.2</td>
<td>$34.65 billion</td>
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<tr>
<td>Fish</td>
<td>0.28</td>
<td></td>
<td>4.2</td>
<td>$5.35 billion</td>
</tr>
<tr>
<td>Birds</td>
<td>0.19</td>
<td></td>
<td>1.5</td>
<td>$1.9 billion</td>
</tr>
<tr>
<td>Mollusks</td>
<td>0.18</td>
<td></td>
<td>1.7</td>
<td>$2.17 billion</td>
</tr>
<tr>
<td>Reptiles &amp; Amphibians</td>
<td>0.11</td>
<td></td>
<td>0.009</td>
<td>$.0011 billion</td>
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<tr>
<td>Mammals</td>
<td>0.04</td>
<td>20</td>
<td>29.4</td>
<td>$37.5 billion</td>
</tr>
<tr>
<td>TOTAL</td>
<td>100</td>
<td>50,000</td>
<td>100</td>
<td>$127.4 billion</td>
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1. Of the 50,000 species introduced into the United States, half are plants. Describe two ways in which exotic plants might be brought to a new environment. How might we help prevent non-native plants from establishing in new areas and posing threats to native communities?

2. Organisms that damage crop plants are the most costly of introduced species; weeds, pathogenic microbes, and arthropods that attack crops together account for half of the costs documented by Pimentel and his colleagues. What steps can we—farmers, governments, and all of us as a society—take to minimize the impacts of invasive species on crops?

3. How might your own behavior influence the influx and ecological impacts of non-native species like those listed above? Name three things you could do to help reduce the impacts of invasive species.