CHAPTER 20

Population Growth and Interactions

Chapter Concepts

20.1 Population Growth

- The density of a population is the average number of individuals in a given area or volume.
- Changes in a population over time can be described quantitatively.
- A J-shaped growth curve is characteristic of a population that is growing at its biotic potential. An S-shaped growth curve is characteristic of a population whose growth is limited by the carrying capacity of its environment.

20.2 Interactions in Ecological Communities

- Intraspecific and interspecific competition may limit the sizes of populations within a community.
- Predator-prey interactions may limit the sizes of producer and consumer populations.
- Mutualism, commensalism, and parasitism are types of symbiosis.
- Succession is a gradual change in community structure over time, due to biotic and abiotic factors.

20.3 Sharing the Biosphere

- Sustainability has social, economic, and environmental dimensions.
- The age structure of a population can be used to predict trends in the growth of the population.
- Earth's carrying capacity for the human population is affected by variables such as trends in birth rates and consumption.

After a long, cold winter in Alberta's wilderness, an abundance of wild grasses and sedges means plenty of food for bison (*Bison bison*) and other herbivores. The warm weather and just the right amount of rain have created ideal growing conditions for flies and mosquitoes. These biting insects have short life cycles, so their populations grow rapidly. The bison have shed their protective winter coats, leaving their skin bare and vulnerable to the insects, which are out for blood and may carry diseases. When the insects die off in the fall, the bison will be more comfortable. Until then, the bison will try to rid themselves of these pests by rolling in marshes or soil. In Chapter 20, you will examine the interactions among populations of different species and discover how different populations change over time. You will also examine the factors that limit the growth of populations, including our own.

Launch Lab

Reproductive Strategies and Population Growth

The female *Aedes* sp. mosquito uses blood sucked from vertebrate animals to nourish her developing eggs. In her lifetime, she may lay up to 600 eggs. These eggs will remain dormant until conditions are favourable for their growth. Once an *Aedes* sp. egg hatches, the larva takes about a week to develop into an adult mosquito, which will live about another 14 days. The bison, on the other hand, is North America's largest mammal and may live up to 40 years. A female bison does not reach sexual maturity until two to three years of age. Then she will give birth two times in three years, usually to only one calf at a time.

Procedure

Use the data in the tables to create two graphs (one for each population) showing population size over time. Then answer the Analysis questions.

Size of a Hypothetical *Aedes* sp. Mosquito Population over One Growing Season

Day	Number of adult mosquitoes
0	20
6	40
12	80
18	160
36	320
42	640
48	1280
54	2560
60	5120
66	10240

Number of Individuals in the Plains Bison (*Bison bison*, subspecies *bison*) Population of Pink Mountain, British Columbia

Year	Estimated number of plains bison
1988	447
1989	494
1990	546
1991	603
1992	666
1993	693
1994	765
1995	845
1996	934
1997	929

Analysis

1. Compare the shapes of your two graphs. Describe the growth of both populations during the given time intervals.
2. Make and record a hypothesis to account for the shape of your graph for the mosquito population and the bison population.

An uncomfortable bison rolls on the ground to try to rid itself of mosquitoes.

SECTION 20.1

Population Growth

Section Outcomes

In this section, you will
- **describe** and **apply** models that represent population density and the distribution of individuals within populations
- **describe** the four main processes that result in changes in population size and **explain**, quantitatively, how these processes are related
- **analyze** population data to determine growth rate and per capita growth rate
- **describe** how a population's biotic potential and the carrying capacity of its habitat determine its pattern of growth
- **compare** *r*-selected strategies with *K*-selected strategies in terms of the life cycles of organisms and patterns of population growth

Key Terms

population density (D_P)
growth rate (*gr*)
per capita growth rate (*cgr*)
biotic potential (*r*)
exponential growth pattern
logistic growth pattern
carrying capacity (*K*)
density-dependent factors
environmental resistance
density-independent factors
r-selected strategies
K-selected strategies

Figure 20.1 Spring is a time of growth for many populations in a community. Hungry bears awaken from their hibernation-like slumber, and plants that have been dormant throughout the winter rapidly reproduce. Herbivores eat the fresh, green shoots, and pollinating insects feed on the flower nectar. The seasons are a source of one constant in ecological communities—change. What else causes change in communities? How does change manifest itself over time?

Quantitative measurements of ecological communities are like snapshots of moments in time. Put together, these snapshots reveal change over time—the one constant in all communities (Figure 20.1). As populations change, so do the communities they comprise. In Chapter 19, you looked at the causes and consequences of genetic changes in populations. In this chapter, you will explore the growth and decline of populations, the distribution of their members, and the mathematical models that are used to create stories from quantitative "snapshots" of their numbers. You will also explore interactions among populations and among members of populations in various environments, and the influence of these interactions on the direction of population change. In addition, you will consider the human activities that, whether intended or unintended, influence the type and degree of change in ecological communities throughout the biosphere.

Density and Distribution of Populations

All populations can be described in terms of two fundamental characteristics: density and distribution. Ecologists use various sampling methods to estimate the density of a population. Then they use their estimate to determine the number of individuals in, and thus the size of, the population. **Population density (D_P)** is defined as the number of individual organisms (*N*) in a given area (*A*) or volume (*V*). As an equation, population density is expressed as

$$D_p = \frac{N}{A} \quad \text{or} \quad D_p = \frac{N}{V}$$

For example, suppose that you sample a population of gophers (Richardson's ground squirrels, *Spermophilus richardsonii*) living in a field one summer. Based on several samples, you find an average of 12 gophers living in an area of 10.0 m^2. The density of the population can be calculated as

$$\frac{12 \text{ gophers}}{10.0 \text{ m}^2} = 1.2 \text{ gophers/m}^2$$

If you know that the field is 200.0 m^2, you can estimate the size of the population:
$(1.2 \text{ gophers/m}^2)(200.0 \text{ m}^2) = 240$ gophers

Similarly, suppose that a 200.0 mL sample of stagnant pond water contains 54 wrigglers (mosquito larvae). The density of the sample is

$$\frac{54 \text{ wrigglers}}{200.0 \text{ mL}} = 0.27 \text{ wrigglers/mL}$$

This information can be used to estimate the size of a mosquito population in an aquatic community at a given time. Since mosquitoes can carry various infectious diseases, large numbers can pose a threat to health. Based on the size of the population, local authorities need to consider controls to keep the mosquitoes in check.

Although one pond-water sample may contain numerous wrigglers, other samples from the same pond may not contain any wrigglers. As you may recall from your field study in Unit 2, you need to know how a population is distributed within its habitat before taking samples to determine the population size. For example, one count of the endangered snail *Physella johnsoni*, which lives only in the hot springs of Banff National Park, indicated that there were 2500 snails/m^2. Since the study area was 9.0 m^2, the population size was estimated to be (9.0 m^2)(2500 snails/m^2) = 23 000 snails. This appeared to be good news. On further study, however, researchers noted that the snails were not evenly distributed throughout their habitat. Instead, they were clumped around the areas where the spring water came out of the ground. Thus, the size of the snail population was much lower than initially predicted.

There are three theoretical *distribution patterns* for populations: *uniform*, *random*, and *clumped* (Figure 20.2). In Thought Lab 20.1, you will explore how population distribution affects population density estimates.

Q 1 Define population density

a) in words

b) in the form of an equation

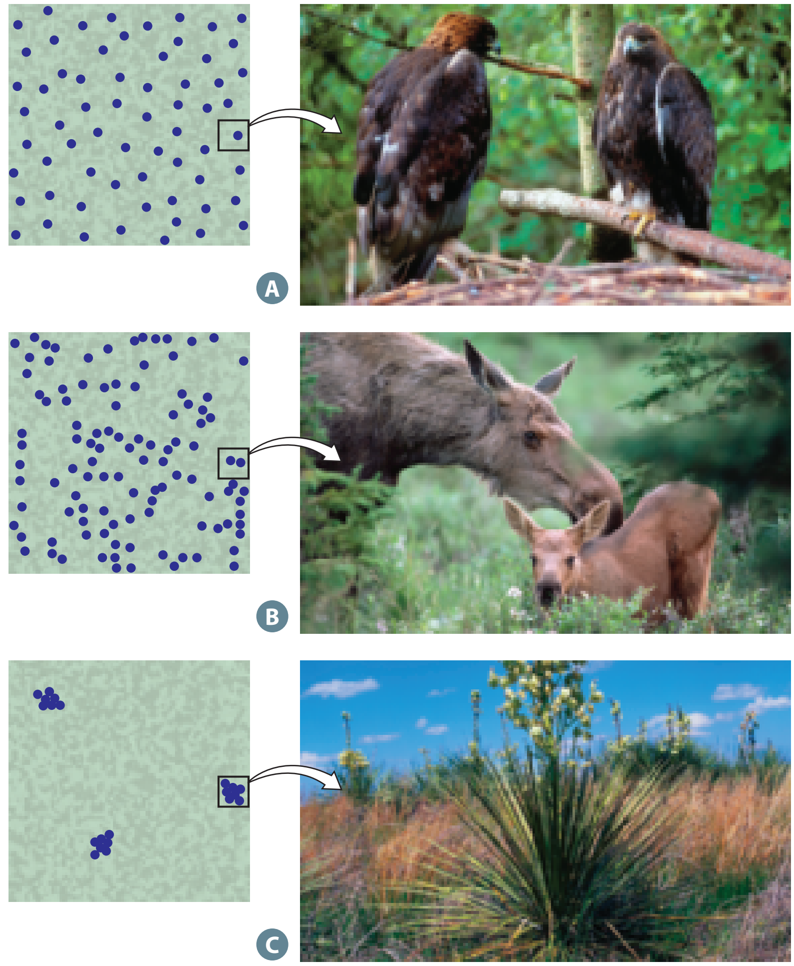


Figure 20.2 Patterns of population distribution. **(A)** Golden eagles (*Aquila chrysaetos*) are territorial, and so pairs are distributed uniformly over a suitable habitat. **(B)** In summer, female moose (*Alces alces*) with calves tend to be distributed randomly over a suitable habitat. **(C)** Soapweed yucca (*Yucca glauca*) can reproduce sexually or asexually by sprouting new plants from the rhizomes (underground stems) of older plants. Therefore, soapweed yucca plants that have reproduced asexually grow in patches, resulting in their clumped pattern of distribution.

Factors That Affect Distribution Patterns

Distribution patterns are influenced by the distribution of resources in a habitat and the interactions among members of a population, or members of a community. For example, *random distribution* can occur when resources are very abundant and population members do not have to compete with one another or, conversely, group together for survival. When a population exhibits random distribution, individuals or pairs of organisms are distributed throughout a suitable habitat with no identifiable pattern. In summer, individual bull moose or female moose

BiologyFile

Web Link
The city of Calgary controls adult mosquito populations by targeting their larvae through a process called larvaciding. What agents are used in the process, and how effective is it?

www.albertabiology.ca
WWW

Thought Lab 20.1 Distribution Patterns and Population Size Estimates

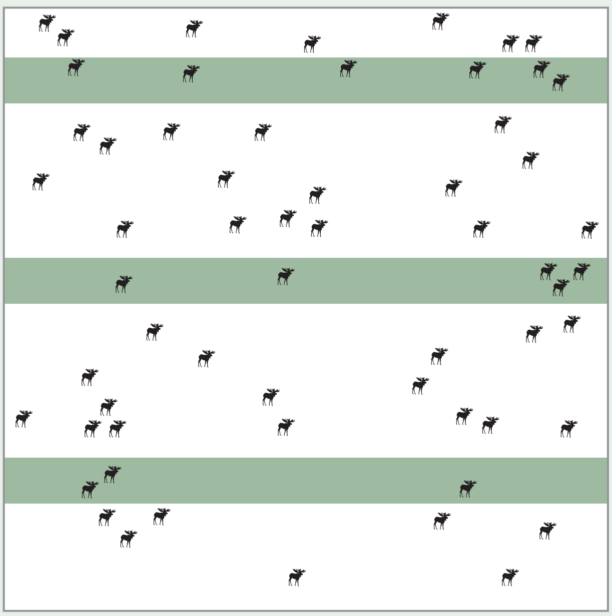
Target Skills

Analyzing data and **applying** mathematical models to determine population size

Applying conceptual models to describe distribution patterns

Asking questions about how distribution patterns influence estimates of population size

Moose (*Alces alces*) tend to be solitary. During the winter, however, moose may congregate in small groups near food and for shelter. In summer, individual bull moose and mothers with their calves may be distributed randomly throughout their habitat. The typical distribution pattern of moose in one habitat compared to another gives scientists clues about the behaviour and ecology of the species. It also helps scientists choose an accurate sampling method for estimating population density. In this activity, you will see how transects (long, narrow areas of land used for ecological study) might be used to sample different moose populations.



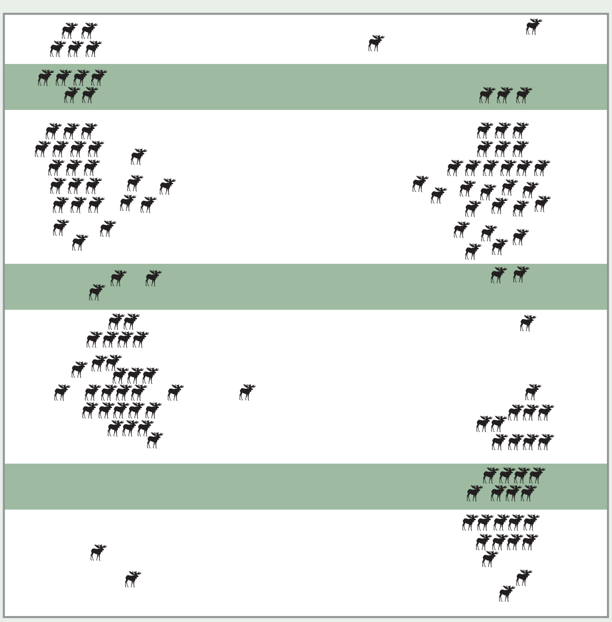
Distribution pattern 1

Procedure

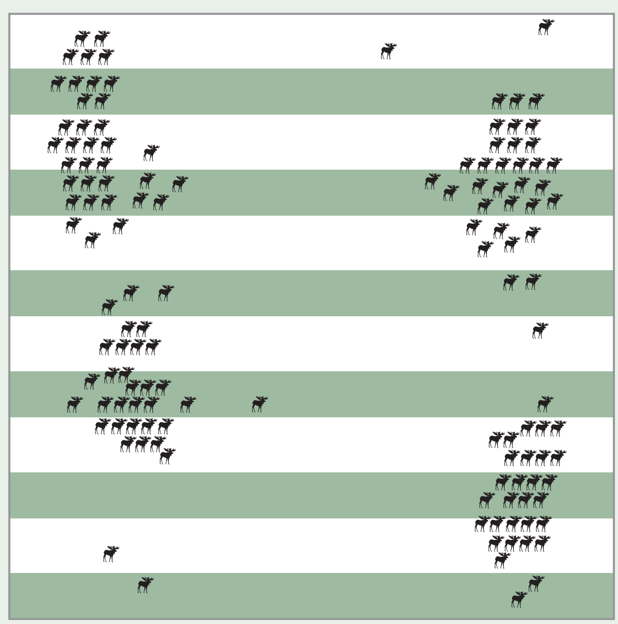
1. Examine the three diagrams of hypothetical moose populations. What are the two different distribution patterns shown?
2. The shaded parts of the diagrams represent the transects that were used to sample each population. Calculate the area per transect. (In these diagrams, 1.0 cm represents 1.0 km.)
3. For each hypothetical population, count the moose within each transect.
4. For each hypothetical population, calculate the average number of moose per transect.
5. Calculate the average density of each hypothetical moose population.
6. Calculate the total study area that is inhabited by one moose population. Estimate the total number of moose in each hypothetical population.

Analysis

1. The actual numbers of moose in the three populations are 60, 133, and 133, respectively. How close were your estimates to the actual sizes of the populations?



Distribution pattern 2



Distribution pattern 3

2. Explain the difference, if any, between your estimate and the actual size of the first population.
3. Explain any differences between your estimates and the actual sizes of the second and third populations.
4. How would you design a sampling experiment on a real population of wild moose? (**Note:** In real life, the time and expenses involved usually restricts the proportion sampled to between 10 and 20 percent of the total area of interest.)

Extension

5. There is concern that an introduced population of moose may deplete the resources in its home range. Why would scientists want to know the density of this population? If you were given the size of this population, how would you calculate its population density?

(*Alces alces*) with calves sometimes exhibit a random distribution pattern. Generally, however, random distribution in nature is rare.

More common is *clumped distribution*, in which members of a population are found in close proximity to each other in various groups within their habitat. Most populations, including humans, exhibit a clumped pattern of distribution, congregating in an area where food, water, or shelter is most abundant. Another example of a species that exhibits clumped distribution is aspens (*Populus tremuloides*). Because aspens reproduce asexually by sprouting new trees from the roots of older trees, they grow in groves, resulting in their clumped pattern of distribution. The Banff springs snail also exhibits clumped distribution. Rather than being evenly distributed throughout their habitat, the snails clump around the areas where the spring water emerges from the ground.

Artificial populations, such as plants growing in orchards or agricultural fields, often exhibit *uniform distribution*, in which individuals are evenly spaced over a defined area. This pattern of distribution is also seen in birds of prey and other organisms that behave territorially to defend their resources and protect their young. The golden eagle (*Aquila chrysaetos*) is an example of a species that exhibits uniform distribution.

In nature, most populations do not perfectly fit any one pattern of distribution. Or, a particular pattern of distribution may be characteristic of a given population, but only at a particular time. Mosquito larvae, for example, tend to exhibit clumped distribution. When they mature into adult mosquitoes, however, they are likely to fly away and distribute randomly. Similarly, moose may congregate in small groups near food and shelter for periods of time during the winter.

Q2 List two factors that influence the distribution patterns of populations.

Q3 Use examples (one for each population distribution pattern) to explain how random distribution is different from clumped distribution and uniform distribution.

Population Growth

A population's size directly depends on how much and how fast it grows. What are the factors that influence population growth? In 2003, the human population of Alberta was 3.2 million. In 2004, the population had increased to about 3.5 million. This means that, compared with 2003, there were 300 000 more births and new residents in Alberta than there were deaths and residents that left the province.

There are four processes that can change the size (number of individuals) of a population (ΔN). Births (b) and immigration (i) (the movement of individuals into a population) cause increases in population size. Deaths (d) and emigration (e) (the movement of individuals out of a population) cause decreases in population size. Therefore, change in population size can be calculated using the following equation:

ΔN	=	$[b + i]$	−	$[d + e]$
change in population size		births + immigration		deaths + emigration

Both immigration and emigration affect the sizes of human populations. In nature, these processes can result in gene flow between populations, but they often occur in equal amounts or in such low numbers that they are difficult to measure or do not significantly affect the sizes of the populations. There are exceptions, however. Some butterflies, for example, form many interconnected populations that exchange members quite frequently. In comparison, the migration of an *entire* population between its wintering and breeding grounds does not, of itself, change the size of the population.

Q 4 Name the four basic processes that cause changes in population size, and write the equation that summarizes their relationship.

The Rate of Population Growth

Just as important as the change in the size of a population is the speed at which the change occurs. An invasive species, for example, may form a population that grows so rapidly that it spreads before it can be contained. Such an increase in population size is called a *population explosion*. Another population may decrease so rapidly and by so much that its decline is referred to as a *population crash*. The change in the number of individuals in a population (ΔN) over a specific time frame (Δt) is known as a population's **growth rate** (*gr*):

$$gr = \frac{\Delta N}{\Delta t}$$

The formula for growth rate can be used to measure increases or decreases in population size over time. For example, in January 1997, the population of Banff Springs snails in the Lower Cave and Basin springs in Banff National Park was estimated to be 3800. Two years later, the population was estimated to be 1800. Therefore, the change in population size was

1800 snails − 3800 snails = −2000 snails

Note that the final value is negative because the population size decreased. Since the change occurred within two years, the growth rate (*gr*) was

$$\frac{-2000 \text{ snails}}{2 \text{ years}} = -1000 \text{ snails/year}$$

In other words, the population decreased at a rate of 1000 snails per year.

The calculation of growth rate does not take into account the initial size of the population. A large population includes more individuals that can reproduce, compared with a small population. Thus, the amount of increase in a large population will be greater than the amount of increase in a comparable small population, as long as nothing limits the growth of either population (Figure 20.3). To compare populations of the same species that are different sizes

Bacterial growth over time

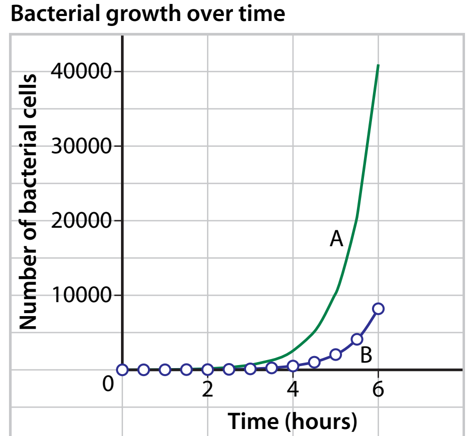


Figure 20.3 Suppose that the same type of bacteria contaminates equal portions of custard in two separate bowls. Initially, there are 10 bacterial cells in bowl A and 2 bacterial cells in bowl B. The bacterial populations double every 30 min. After 6 h at room temperature, the population in bowl A contains nearly 33 000 more bacterial cells than the population in bowl B.

or live in different habitats, the change in population size can be expressed as the rate of change per individual. This measurement, the **per capita growth rate** (***cgr***), can be determined by calculating the change in the number of individuals (ΔN) relative to N (the original number of indiviuals), and then dividing this change in the number of individuals by the original number in the population (N):

$$cgr = \frac{\Delta N}{N} \quad \text{or} \quad cgr = \frac{N_{\text{final}} - N}{N}$$

Suppose that, in a town of 1000 people, there are 50 births, 30 deaths, and no immigration or emigration in a year. During this time interval, the per capita growth rate (*cgr*) for the population is

$$\frac{50 - 30}{1000} = 0.02$$

Like the growth rate, the per capita growth rate can be negative if deaths and emigration outnumber births and immigration. Study the Sample Problems on page 710, and then do the Practice Problems that follow.

5. Explain the difference between the growth rate of a population and the per capita growth rate of a population.
6. A deer population increases in size from 2000 to 2300 individuals over one year. Calculate the growth rate of the population during this time interval.
7. Determine the per capita growth rate of the deer population in question 6.

Factors That Affect Population Growth

As you may recall from Chapter 3, both biotic and abiotic factors limit the growth of a population. One category of biotic limiting factors includes the physiological and physical characteristics of a species that determine how fast and how often it can reproduce. The ability of a habitat to support a population, due to abiotic and biotic factors, also limits the size of a population.

Biotic Potential

Each species has an intrinsic rate of growth that is possible given unlimited resources and ideal living conditions. The highest possible per capita growth rate for a population is called its **biotic potential** (***r***). Factors that determine a species' biotic potential include

- the number of offspring per reproductive cycle
- the number of offspring that survive long enough to reproduce
- the age of reproductive maturity and the number of times that the individuals reproduce in a life span
- the life span of the individuals

As shown in Figure 20.4, a population that is growing at its biotic potential would be expected to grow exponentially. The brief lag phase, followed by a steep increase in the growth curve—called an **exponential growth pattern**—can be described as a J-shaped curve. The biotic potentials of micro-organisms, small animals, and certain plants are relatively easy to assess in a laboratory. The exponential growth rate of these types of organisms under ideal conditions can be observed in micro-environments, such as broth cultures of bacteria. The biotic potentials of other species are harder

Change in number of organisms over time in a population growing at its biotic potential

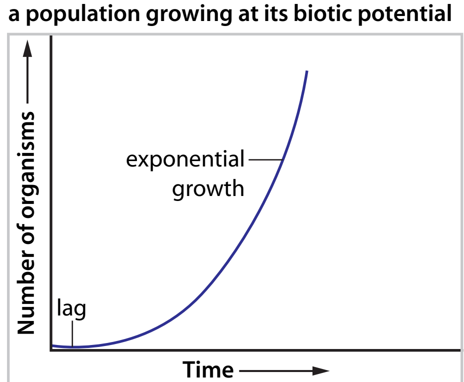


Figure 20.4 Any population, whether plankton, insects, or whales, growing at its biotic potential will grow exponentially, resulting in a J-shaped growth curve.

Sample Problems

Sample Problem 1

A collared pika (*Ochotona collaris*) population dropped from exactly 25 individuals in 1998 to 5 individuals in 2000. Calculate the growth rate of this population from 1998 to 2000.

What Is Required?

To determine the growth rate (gr) of the collared pika population from 1998 to 2000

What Is Given?

The values needed to calculate the change in the number of individuals in a population size (ΔN): The original number of individuals is 25.0. The final number of individuals is 5.00.

The values needed to calculate the change in time (Δt): The beginning of the time frame is 1998. The end of the time frame is 2000.

Plan Your Strategy

Calculate ΔN.

Calculate Δt.

Calculate $gr = \frac{\Delta N}{\Delta t}$.

Act on Your Strategy

Step 1

$$\Delta N = \text{final number of individuals} - \text{original number of individuals}$$
$$= 5.00 - 25.0$$
$$= -20.0 \text{ individuals}$$

Step 2

$$\Delta t = \text{final time} - \text{initial time}$$
$$= 2000 - 1998$$
$$= 2 \text{ years}$$

Step 3

$$gr = \frac{\Delta N}{\Delta t}$$
$$= \frac{-20.0 \text{ individuals}}{2 \text{ years}}$$
$$= -10 \text{ individuals/year}$$

The growth rate of the collared pika population was −10 individuals per year. In other words, the population dropped at a rate of 10 individuals per year.

Check Your Solution

$$gr = \frac{\Delta N}{\Delta t}$$
$$(gr)(\Delta t) = \Delta N$$
$$(-10 \text{ individuals}/\cancel{\text{year}})(2\ \cancel{\text{years}}) = -20 \text{ individuals}$$
$$-20 \text{ individuals} = -20 \text{ individuals}$$

Sample Problem 2

A population of 26 caribou (*Rangifer tarandus*) was introduced onto a predator-free island in Alaska in 1910. For the next 25 years, the per capita growth rate of the population was 75.9. In about 1935, resources became limited and the population crashed. Calculate the number of caribou on the island just before the population crashed.

What Is Required?

To determine the size of the island caribou population after the given time interval

What Is Given?

The value of the original number of individuals in the population (N): 26 caribou

The per capita growth rate (cgr) for the population over 25 years: 75.9

Plan Your Strategy

Rearrange the formula for per capita growth rate (cgr) to solve for ΔN.

Find the value of ΔN.

Add the original number of individuals in the population (N) to the change in the number of individuals (ΔN).

Round the answer to the correct number of significant digits.

Act on Your Strategy

Step 1

$$cgr = \frac{\Delta N}{N}$$
$$\Delta N = (cgr)(N)$$

Step 2

$$\Delta N = (75.9)(26 \text{ caribou})$$
$$= 1973.4 \text{ caribou}$$

Step 3

$$\text{Final number of individuals in population} = \Delta N + N$$
$$= 1973.4 \text{ caribou} + 26 \text{ caribou}$$
$$= 1999.4 \text{ caribou}$$

Step 4

$1999.4 \text{ caribou} \approx 2.0 \times 10^3 \text{ caribou}$

There were about 2000 caribou on the island.

Check Your Solution

$$\Delta N - N = 2000 \text{ caribou} - 26 \text{ caribou}$$
$$= 1974 \text{ caribou}$$
$$cgr = \frac{\Delta N}{N}$$
$$= 1974\ \cancel{\text{caribou}} / 26\ \cancel{\text{caribou}}$$
$$= 75.9$$

Practice Problems

1. Suppose that a sample of beef broth initially contains 16 bacterial cells. After 4.0 h, there are 1.6×10^6 bacterial cells in the sample. Assuming that the bacteria reproduce at a constant rate, calculate the growth rate of the bacterial population for the given time interval.
2. The Alberta greater sage grouse population was about 4375 in 1970. By 2002, the population was estimated to be only about 350 birds. Assuming that the population decreased at a constant rate, calculate the growth rate for the population from 1970 to 2002.
3. *Lemna minor*, a species of duckweed, can reproduce to form new plants very quickly. Suppose that a small backyard pond contains 25 *L. minor* plants, and the expected growth rate of the population is 1.0×10^2 plants per day. Predict how many *L. minor* plants the pond will contain after 31 days.
4. According to population surveys of piping plover (*Charadrius melodus*), there were 34 of these birds on Dowling Lake, Alberta, in 1992. The next year, the population of piping plover on Dowling Lake was 39. Calculate the per capita growth rate for the piping plover population during the entire survey period.
5. Between 1996 and 2001, Cochrane, Alberta, was the fastest growing municipality in Canada, with a per capita growth rate of 0.589. There were about 7424 people living in Cochrane in 1996. How many people lived there in 2001?
6. The experimentally re-introduced grey wolf population of Idaho was 310 at the beginning of 2004. Over the year, 112 pups were born and 49 individuals died or were removed from the study area. Calculate the per capita growth rate of this grey wolf population during the study period.

to assess because their ideal growth conditions are more difficult to create. Scientists can make only hypothetical estimates of their biotic potentials.

Q8 Define biotic potential, and give its symbol.

Q9 Name four factors that determine the biotic potential of a species.

Q10 What is an exponential growth pattern? What is its shape in a graph?

Q11 Explain how biotic potential and exponential growth are related.

Carrying Capacity

In the beginning, the growth of a small population is slow, since there are only a few individuals to reproduce (Figure 20.5). This initial stage is called the *lag phase*. As the numbers of individuals in the population increase, the population will experience an exponential rate of growth. The birth rate during the exponential growth phase is much greater than the death rate, so the population size will increase rapidly. Under natural conditions, however, this rapid growth rate cannot continue indefinitely. Eventually, competition for resources and other limiting factors will slow the rate of growth. Lack of food, for example, will limit the energy that is available for reproduction. At this stage, called the *stationary phase*, the birth rate and death rate are equivalent. This pattern is comparable to filling an unplugged sink with water. The sink fills slowly at first, and then faster and faster. When the level of water reaches a certain point, a much smaller amount of water can be added to keep the sink full.

The pattern of population growth that is illustrated in Figure 20.5 is an S-shaped (sigmoidal) curve known as the **logistic growth pattern**. The green line running through this curve represents the habitat's **carrying capacity** (***K***)—the theoretical maximum population size that the environment can sustain over an extended period of time. In other words, the carrying capacity represents the number of individuals in a population that can live in a given environment without depleting the resources they need or harming their habitat or themselves. As a habitat changes from season to season, Effect of environmental resistance on population growth

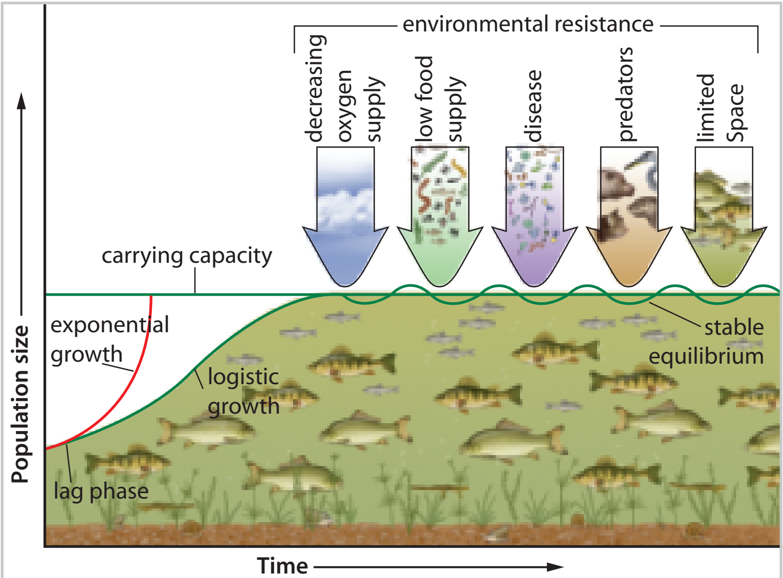


Figure 20.5 As a population increases in size, limiting factors such as disease, predation, and competition for limited resources reduce the amount of energy that is available for reproduction. This causes the growth rate of the population to decrease.

or from year to year, the carrying capacity also changes. Over time, population size may fluctuate around the carrying capacity of the habitat in a *stable equilibrium*.

The factors that limit a habitat's carrying capacity can be categorized as density-dependent or density-independent. **Density-dependent factors** are biotic. When a population is small and well below the carrying capacity of the habitat, density-dependent factors do not limit growth. The impact of density-dependent factors on a population increases with the density of the population. For example, parasites and disease spread more easily in dense populations. Also, predation becomes a more important limiting factor for prey populations as they get larger and denser.

Density-independent factors are abiotic and include harsh weather, drought, floods, and forest fires. Density-independent factors limit the growth of a population, regardless of its size or density. A cold snap, for example, kills all or most of the mosquitoes in a streambed whether the population is small or large.

The combined effects of various, interacting limiting factors is described as the **environmental resistance** to population growth. Environmental resistance prevents a population from growing at its biotic potential and determines the carrying capacity of the habitat. The arrows in Figure 20.5 illustrate how limiting factors such as predation and disease apply environmental resistance to population growth, maintaining growth at or near the carrying capacity of the habitat. (In Section 20.2, you will learn more about the effects of some limiting factors.)

12 Define carrying capacity, and give its symbol.

13 Explain, using at least two examples, the differences between density-dependent factors and density-independent factors.

14 What is environmental resistance? How does it affect populations?

Life Strategies

In an unstable environment, it can be advantageous to expend energy in order to reproduce rapidly while conditions are favourable. The growth of infectious bacteria that multiply rapidly once they enter the body, is an example. In contrast, the long life span of the wood bison and the small number of offspring per parent may be more useful adaptations in a relatively stable environment. These adaptations of the wood bison are two of many factors that can permit a population to exist close to the carrying capacity of its habitat without crashing.

The different *life strategies* of rapidly growing bacteria and wood bison can be used to represent two extremes along a continuum. The bacteria, and other species that reproduce close to their biotic potential (r), represent one end of the continuum. Such species are said to have ***r*-selected strategies**. Species with r-selected strategies have a short life span and an early reproductive age, and they

Figure 20.6 Since 1986, ecologists with La Trobe University in Australia have been tagging Antarctic fur seal pups similar to this one from separate populations at Macquarie Island in the sub-Antarctic. The scientists are trying to determine if the length of time that pups nurse affects their survival.

produce large broods of offspring that receive little or no parental care. Insects, annual plants, and algae typically have *r*-selected strategies. They take advantage of favourable environmental conditions, such as the availability of food, sunlight, or warm summer temperatures, to reproduce quickly. In Alberta's climate, for example, these organisms experience exponential growth in the summer, but die in large numbers as the summer ends.

At the other end of the continuum are populations that live close to the carrying capacity (*K*) of their habitats, and thus are described as having ***K*-selected strategies**. Mammals such as wood bison, northern fur seals (*Callorhinus ursinus*), and eurasian badgers (*Meles meles*), and birds such as tawny owls (*Strix aluco*), exhibit typical *K*-selected life strategies. They have few offspring per reproductive cycle, and one or both parents care for the offspring when young. The offspring take a relatively long time to mature and reach reproductive age, and they live a relatively long time. Also, they tend to have large bodies, compared with organisms that have *r*-selected strategies. A typical *K*-selected life strategy is to produce few offspring, but to invest a large amount of energy into helping the offspring reach reproductive age.

In reality, most populations have a combination of *K*-selected strategies and *r*-selected strategies. Consider, for example, any species of coniferous tree. Coniferous trees are large and can live many years, but they produce hundreds of gamete-bearing seeds. In addition, a population can only be properly described as *K*-selected or *r*-selected when it is compared to another population. A gopher population, for instance, could be described as being a *K*-selected population compared to a mosquito population. On the other hand, compared to a bison population, a gopher population would be better described as being *r*-selected. Gophers live for only three to six years and females produce one litter of about seven pups per year.

Recognizing the various *K*-selected and *r*-selected strategies of a species can be used to predict the success of a population in a particular habitat. For example, scientists who are studying two populations of Antarctic fur seals (*Arctocephalus gazella*) on the same island have observed that mother seals nurse their pups for 10 months in one population, while pups are weaned at four months in the other population. The scientists would like to find out if the greater investment of time and energy given to lactation influences the survival and reproductive success of the seal pups (Figure 20.6).

In Thought Lab 20.2, you will consider the impact of *K*-selected strategies on the survival of grizzly bear populations.

Q 15 Create a table to compare the characteristics of populations with typical *r*-selected and *K*-selected life strategies.

Thought Lab 20.2

What Limits the Growth of Grizzly Bear Populations?

Target Skills

Calculating and **interpreting** population density and changes in population size

Evaluating the effects of human activities on grizzly bears

Recognizing the intrinsic factors that limit grizzly bear population growth

Records indicate that in the 1800s grizzly bears (*Ursus arctos*) occupied most of the region encompassed by the province of Alberta. As settlers moved west, however, hunting and the development of land for agriculture and, later, industry and recreation led to the decline of the grizzly bear population. In the 1960s, scientists concluded that conservation action was needed to preserve Alberta's grizzly bear population, which is now limited to the western edge of the province.

Statistics show that over 80 percent of all bear deaths are related to human activities. Humans present two threats to the grizzly bear population: disruption of habitat and grizzly bear mortality. The bears require a wide home range—up to 500 km^2 for females and more for males—to meet their dietary needs. They have large energy requirements, which they fulfill by eating grasses, sedges, berries, ants, and ungulates. Fragmentation of their habitat due to the building and use of new roads, or industrial or recreational facilities, is detrimental to their population. Like other large mammals, grizzly bears do not adapt well to major changes in their environment. Can humans and grizzly bears share the same environment?

Procedure

Using the data in the first table, draw a graph that shows the change in size of the Alberta grizzly bear population outside the National Parks over time. Then complete the following Analysis questions.

Analysis

1. To manage the grizzly bear population better, the government of Alberta introduced a hunting lottery that awards a limited number of grizzly bear hunting licenses. Predict the year that this regulation was introduced.

Number of Grizzly Bears in Alberta, Outside the National Parks

Year	Population size
1988	575
1989	536
1990	547
1991	638
1992	669
1993	686
1994	700
1995	735
1996	765
1997	776
1998	807
1999	833
2000	841

Source: Alberta Wildlife Status Reports, Alberta Sustainable Resource Development, 2002

2. The number of grizzly bear deaths in Alberta from 1976 to 1988 was estimated to be 581. Only 281 deaths were recorded from 1988 to 2000. How does this information affect the prediction you made in question 1? Explain your answer.
3. Determine the per capita growth rate (*cgr*) for each of the following time intervals: 1991 to 1992, 1997 to 1998, and 1998 to 1999. Suggest why the *cgr* has changed over time.
4. Population counts were made in several bear-management regions around the province. Some of the data are shown in following table.
   a) For each region, determine the number of grizzly bears per 1000 km^2.
   b) Compare the densities for the three regions. Suggest three reasons for the differences, if any. Explain your thinking.

Grizzly Bear Population Sizes in Alberta

Region	Area (km^2)	Bear population
A	14 128	31
B	6 089	44
C	22 840	168

Source: Alberta Wildlife Status Reports, Alberta Sustainable Resource Development, 2002

5. Very few grizzly bears die of old age. What are two other possible causes of death, not associated with human activities?
6. Studies have shown that male grizzly bears will cross roads and use underpasses to forage in a better environment. Females tend to remain in more restricted areas.
   a) How might the movement of male and female grizzly bears in their habitat affect genetic diversity in the population?
   b) How would this behaviour influence the per capita growth rate of the population?
7. Grizzly bears reach sexual maturity at five years of age. When food is abundant, females average two cubs per litter every other year. With inadequate nutrition, females produce fewer cubs.
   a) Compared with mosquitoes, how would you describe the life strategy of grizzly bears?
   b) Explain why the biotic potential of grizzly bears is relatively low.
   c) How might grizzly bears' low biotic potential present challenges for people who are working to conserve the grizzly bear population?
8. Near Lake Louise, Alberta, there is a road sign that asks drivers on the highway to reduce their speed from 90 to 70 km/h along a 15 km stretch where grizzly bears are known to forage for food, especially at dusk and dawn.

   Do you think that lowering the speed limit along this stretch of highway is a reasonable action? Would the installation of underpasses along this stretch of highway be a better alternative? Compare the advantages and disadvantages of each option. What questions might you want answered before making a decision about this issue?
9. One report concluded that people must "find a way" to prevent the Trans-Canada highway from being a barrier to grizzly bear migration. List the stakeholders in this issue. Based on the point of view of one of these stakeholders, suggest what actions could be taken to overcome the fragmentation of the grizzly bear's habitat. Share your ideas on this issue in a class discussion.

Section 20.1 Summary

- The density of a population can be described and estimated quantitatively.
- Population density is defined as the number of organisms that make up a population in a given area or volume at a particular time: $D_p = \frac{N}{A}$ or $D_p = \frac{N}{V}$.
- There are three theoretical patterns of distribution: random, clumped, and uniform. These patterns are influenced by the distribution of resources in a population's habitat, as well as by the interactions among members of different communities in this habitat.
- Four processes that cause changes in population size are births, immigration, deaths, and emigration: $\Delta N = (b + i) - (d + e)$. Births and immigration increase the size of a population, while deaths and emigration decrease its size.
- The rate at which the size of a population changes is called the growth rate (*gr*) of the population. It can be described using the equation $gr = \frac{\Delta N}{\Delta t}$.
- Because the growth rate does not take the initial number of individuals in a population into account, the per capital growth rate (*cgr*) may be used to compare populations of the same species by describing the change in the number of individuals of a population in terms of the rate of change per individual: $cgr = \frac{\Delta N}{N}$ or $cgr = \frac{N_{final} - N}{N}$.
- The environment limits population growth by changing birth and death rates.
- Factors that affect population size and growth include biotic factors such as resources, disease, and predators, and abiotic factors such as floods, temperature, and hurricanes.

- Because the effects of biotic factors are often influenced by population density, biotic factors are described as being density-dependent.
- The effects of abiotic factors are not influenced by population density, so they are called density-independent factors.
- Given unlimited resources and ideal living conditions, the highest possible per capita growth rate for a population is referred to as its biotic potential (r).
- A population growing at its biotic potential grows exponentially, which can be represented graphically as a J-shaped curve.
- Since unlimited resources and ideal living conditions are rare in nature for any length of time, populations are bound by a theoretical maximum size that their habitat can support for an extended period of time. This is the carrying capacity of the habitat.
- Populations that grow in an environment where food or other resources are limited can be represented graphically with an S-shaped curve, called a logistic growth pattern. The combined effect of these limiting factors is described as environmental resistance to population growth.
- A population in a given environment can be described as r-selected or K-selected in comparison to another population.
- K-selected populations typically consist of individuals living close to the carrying capacity of their habitat, with long life spans, later reproductive ages, and small numbers of offspring.
- r-selected populations typically consist of individuals growing close to their biotic potential, with short life spans, early reproductive ages, and large numbers of offspring.
- The concepts of r-selection and K-selection are two extremes of a continuum. Most populations appear somewhere between these two extremes.

Section 20.1 Review

1. Why do scientists often need to estimate the size of a population, rather than counting each member individually?
2. Define population density.
3. Explain why population density is not always a reliable tool for estimating the number of individuals in a population.
4. How might the abundance and distribution of food in a habitat influence how a species is dispersed in this habitat?
5. Compare birth rates and death rates for a population during the lag, exponential, and stationary phases of a logistic growth pattern.
6. List three limiting factors that would be part of the environmental resistance in a forested habitat. Explain how each factor could limit the growth of a population.
7. List three factors that determine the biotic potential of a particular species. Explain how each factor affects the biotic potential of this species.
8. On the same graph, draw a typical exponential growth curve and a typical logistic growth curve. On the correct curve, label the point at which the growth of the population has begun to slow down and the point at which the population has reached the carrying capacity of its habitat.
9. Scientists refer to populations with r-selected life strategies as opportunistic populations and populations with K-selected life strategies as equilibrium populations. Use the characteristics of each type of strategy to explain how scientists came up with these terms.

SECTION
20.2
Interactions in Ecological Communities

Section Outcomes

In this section, you will
- **describe** the interactions among population members and among members of the different populations within a community
- **design** investigations to measure the effects of intraspecific and interspecific competition on the growth of plants
- **explain** how producer-consumer interactions affect population growth
- **describe** defense mechanisms, such as protective coloration, that have evolved within populations
- **understand** that symbiosis includes mutual, commensal, and parasitic relationships
- **distinguish** between primary and secondary succession

Key Terms

intraspecific competition
interspecific competition
predators
prey
protective coloration
symbiosis
mutualism
commensalism
parasitism
succession
primary succession
pioneer community
climax community
ecological disturbance
secondary succession

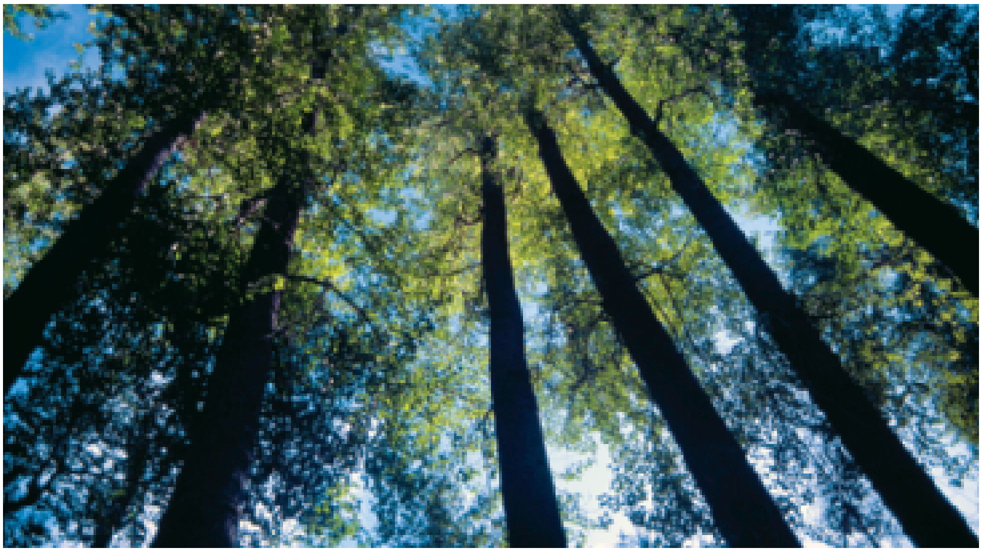


Figure 20.7 Following a flood, some of the cottonwood tree seeds on the forest floor will germinate. Only a few of the seedlings will mature into trees.

An *ecological community* is an association of interacting populations that inhabit a defined area. The plant community in a boreal forest, or the algal, bacterial, insect, and fish populations in a stream are examples of ecological communities. In any community, individuals of many populations may compete for limited resources. Members of some species may prey on members of other species. On the other hand, members of one species may be adapted to live closely with members of another species, improving the chances of survival for both species. The interactions among individuals, within the same population or from different populations, are a driving force behind population dynamics—the changes that occur in populations over time.

Intraspecific Competition

With sufficient moisture, the seeds on the floor of a cottonwood (*Populus* sp.) forest will begin to germinate (Figure 20.7). Even a small area of the forest will contain thousands of seeds. Each seed requires water, nutrients, sunlight, and sufficient space to grow, mature, and survive. Only a few of the seedlings will be able to compete successfully to obtain what they need from the limited resources that are available to them. The competition for limited resources among members of the same species is called **intraspecific competition**.

Intraspecific competition is a density-dependent factor that limits the growth of a population. Intraspecific competition plays an important role in natural selection, as well. For example, some individuals may have a competitive advantage, such as being able to grow longer roots to absorb more water. These individuals will be more likely to survive long enough to reproduce, thereby passing on this competitive trait to their offspring. Similarly, members of an animal population may compete with one another for food or shelter.

When individuals are in competition for limited resources, why is it that parents do not out-compete their offspring? In fact, in many species, if the offspring did not disperse away from their parents, the offspring and parents would be in competition. Many fungi, for example, produce spores that can be carried on the wind to faraway locations.

BiologyFile

FYI

You may be unfamiliar with the notation "sp.," which can be used when providing the name of a species. When the specific name of a species is not known or has not yet been determined, biologists use the abbreviation "sp." For example, "*Felis* sp." refers to a species that belongs to the genus *Felis* (a genus of cats).

Figure 20.8 The light, fluffy seeds of the aspen poplar tree are easily carried by the wind to locations far away from the parent.

Similarly, plants such as the aspen poplar (*Populus tremuloides*) produce wind-borne seeds (Figure 20.8). Some plants produce fleshy fruit around their seeds. Animals that eat the fruit digest the fleshy part but release the seeds in their feces, sometimes kilometres away from the parent plants.

Developing insect offspring undergo a complete metamorphosis. This means that the offspring go through a larval stage, in which they look completely different from the adults. The cabbage white butterfly (*Pieris rapae*), shown in Figure 20.9, begins life as a caterpillar that feeds on the leaves of plants from the mustard family, such as broccoli and cauliflower. The adult butterfly of this species feeds on flower nectar from plants such as clover, mustards, and dandelions. Since the adults and young have different needs, competition between them is reduced.

Interspecific Competition

Competition also occurs between members of different species in the same community. For example, white spruce (*Picea glauca*) may compete with lodgepole pine (*Pinus contorta*) for light and living space. Eventually, the white spruce may take over. Competition between two or more populations for limited resources, such as nutrients, light, or living space, is referred to as **interspecific competition**.

Due to interspecific competition, no two species can share the exact same ecological niche. As you may recall from Chapter 3 (see page 97), an organism's ecological niche is defined by its habitat and role within the community. An organism's ecological niche includes all the biotic and abiotic factors that are required for the organism to survive, as well as the organism's interactions with other species. When populations share overlapping niches, they compete for limited resources. Interspecific competition is less fierce, however, if the populations have even slightly different niches. For example, five species of warbler can successfully forage in the same species of spruce tree, because each species of warbler tends to feed on insects that are found in a different part of the tree. As well, each species flies in a different pattern to catch insects.

Often, when a non-native species is introduced into an environment, it competes with the native species. Sometimes, the native species compete

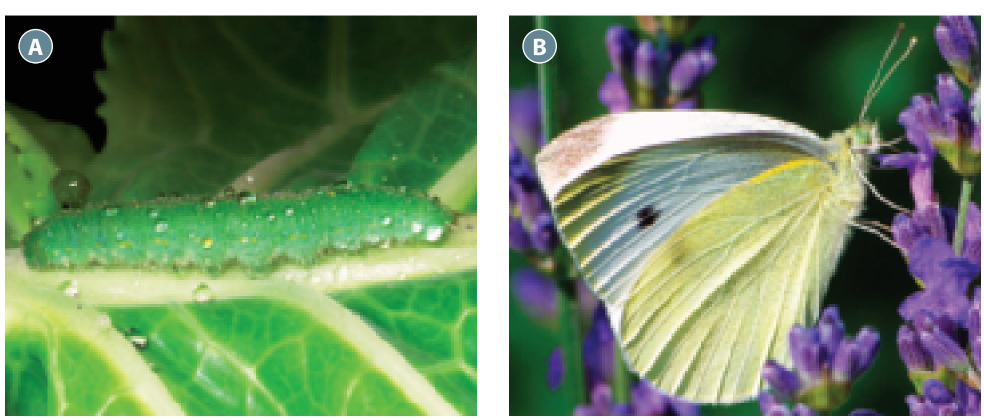


Figure 20.9 Larval **(A)** and adult **(B)** forms of the cabbage white butterfly, *Pieris rapae*. This insect was introduced to Quebec from Europe in the mid-1850s, and it is now found throughout much of North America.

successfully against the introduced species, which dies out. Other times, however, the introduced species takes over the niches of the native species, thereby changing the structure of the ecological community. For example, the wetlands in Canada and the United States are particularly vulnerable to varieties of reed canary grass (*Phalaris arundinacea*) that have been introduced since the 1800s (Figure 20.10). Although there are varieties of reed canary grass that are native to North America, the introduced varieties are extremely invasive. These invasive species frequently out-compete many native species, thus reducing plant diversity in the wetlands. Stands of the invasive reed canary grass are thought to make poor nesting and feeding sites for wetland animals.

Figure 20.10 Eurasian varieties of reed canary grass sometimes take over areas that have been cleared of another, more readily identifiable invasive species—purple loosestrife (*Lythrum salicaria*). Purple loosestrife (shown here) is considered an ornamental grass in Asia and Europe, from where it was introduced. Often, both introduced species grow together, making the reed canary grass difficult to detect.

16 Distinguish between intraspecific competition and interspecific competition.

17 Explain how intraspecific competition limits the growth rate of a population.

18 State what can happen when a non-native (introduced) species competes with native species.

Producer-Consumer Interactions

Not all interspecific interactions in a community are competitive. Primary producers have a direct relationship with the primary consumers that eat them. Primary consumers, in turn, have a direct relationship with their predators, the secondary consumers. **Predators** are organisms that kill and consume other organisms, known as **prey**.

The producer-consumer relationship puts selective pressure on both partners, with the more successful consumers driving the natural selection of the producers. In other words, producers that are more difficult to catch or less desirable to consume are more likely to survive. In addition, like any important food source, the scarcity of a producer species is a factor that can limit a consumer species' population. On the other hand, a dense population of consumers may control the growth of producer populations.

For example, some grey wolves prey mainly on elk (*Cervus elaphus*). Following the extirpation of grey wolves from Banff National Park in the 1970s, the elk population of the park soared. With the increased presence of elk in and around the town of Banff, conflicts between the elk and humans became more common. In addition, ecologists found that the elk were overgrazing and damaging willow (*Salix* sp.) and aspen trees. Ecologists linked the loss of these trees, in turn, to declines in local populations of songbirds and beavers (*Castor canadensis*). To help limit the Banff elk population, grey wolves were encouraged back into the area. By 2003, the elk population had declined significantly, indicating that, along with re-conditioning elk to be wary of people, the strategy of bringing back the elk's major predator was working.

Predator-prey interactions are one factor in the *boom or bust* cycles observed in populations of some northern species. Figure 20.11 on page 719 shows two such population cycles. Hypothetically, the larger a prey population is, the more food that is available to its predators. Thus, the predators have more energy to reproduce

BiologyFile

Web Link
Russian scientist Georgyi F. Gause found that if two species of *Paramecium* occupied the same niche, eventually one would out-compete the other, resulting in the loss of one of the populations. How does this evidence support the concept of *competitive exclusion*?

www.albertabiology.ca
WWW

INVESTIGATION 20.A

Target Skills

Designing and **performing** experiments to demonstrate intraspecific and interspecific competition

Working as a team to communicate ideas and information

Interspecific and Intraspecific Competition Among Seedlings

Both *intra*specific competition and *inter*specific competition limit the growth of populations. Gardeners consider the effects of both kinds of competition when planning out garden plots. In this investigation, you will design two experiments. One will demonstrate the effects of intraspecific competition, and the other will demonstrate the effects of interspecific competition.

Part 1: Intraspecific Competition

Question

How does intraspecific competition affect the growth of individuals in a population?

Safety Precautions

The sprouts may become contaminated. Do not eat them.

Hypothesis

Make and record a hypothesis about how increasing intraspecific competition will affect the growth of individuals in a population.

Materials

- seeds (such as basil, marigold, radish, grass, lettuce, bean, or clover seeds)
- vermiculite or potting soil
- flower pots
- scissors
- ruler
- balance

Experimental Plan

1. With your group, establish the manipulated and responding variables.
2. State and record your hypothesis.
3. Using some of the listed materials as a starting point, design a procedure for your experiment. Be sure to include controlled variables in your procedure. Also include the criteria you will use to measure your experimental results.
4. Create a data table for your results. Decide how you will later present the data.
5. Once your group has agreed on the plan, have your teacher approve it.

Data and Observations

Conduct your investigation, and record your results. Then present the data in a graph.

Part 2: Interspecific Competition

Question

How does interspecific competition affect the growth of individuals in different populations?

Safety Precautions

The sprouts may become contaminated. Do not eat them.

Hypothesis

Make and record a hypothesis about the effect of interspecific competition on the growth of individuals in different populations.

Experimental Plan

Using some of the suggested materials listed in Part 1, design an experiment to demonstrate interspecific competition among populations of seedlings. Follow the same steps to plan your investigation that you followed in Part 1.

Data and Observations

Conduct your investigation, and record your results. If possible, present the data in a graph.

Analysis

1. How did you manipulate the degree of intraspecific competition in your experiment in Part 1?
2. Were the criteria you used to measure your experimental results and evaluate the differences in the seedlings' growth effective? Explain.
3. Consult with your classmates to see which procedures provided the most effective demonstrations of
   a) intraspecific competition
   b) interspecific competition
4. Critique your experimental plans for Part 1 and Part 2. What changes would you make if you could conduct this investigation again?

Conclusions

5. How did the intraspecific competition in Part 1 affect the growth of individual seedlings?
6. In Part 1, were you able to detect the effect of intraspecific competition on the entire population that you planted? If so, explain how and describe your results. If not, how would you expect intraspecific competition to affect a population?
7. In Part 2, how did interspecific competition affect the growth of the seedlings in the competing populations? Provide an explanation for these results.
8. In Part 2, did one population compete better overall? If so, which one? Provide an explanation for this result.
9. Your results were based on the germination of seeds. The death rate of plants is highest at this stage. Hypothesize how your results might have been different if you had used adult plants in both Part 1 and Part 2. How could you test your hypotheses?

and care for their young. This allows the predator population to increase. With a greater number of predators, the prey population will decline, resulting in more intense competition among the predators for food, which becomes a limiting factor. The predator population therefore declines, and, with fewer predators, the prey population increases.

The results of extensive, long-term ecosystem studies suggest, however, that predator-prey interactions do not fully explain population cycles. Populations of snowshoe hare (*Lepus americanus*) and Canada lynx (*Lynx canadensis*) follow boom or bust cycles that each last about 10 years. Figure 20.12 shows the number of Canada lynx and snowshoe hare pelts from the Canadian Arctic that were traded to the Hudson Bay Company over 100 years. The number of pelts would have been affected by the demand for pelts, the number of trappers, and the location of the traps. Nevertheless, the hare and lynx populations fluctuated in cycles that were too regular to be due to abiotic factors. Furthermore, the increases and decreases in the lynx population closely followed increases and decreases in the hare population. This observation

Predator-prey population cycles

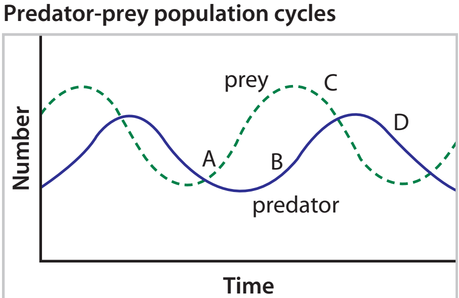


Figure 20.11 A simplified graph of predator-prey population cycles. An increase in prey increases the resources that are available to the predators **(A)**, so the predator population increases **(B)**. This leads to a reduction in the prey population **(C)**, followed by a reduction in the predator population **(D)**. And the cycle continues.

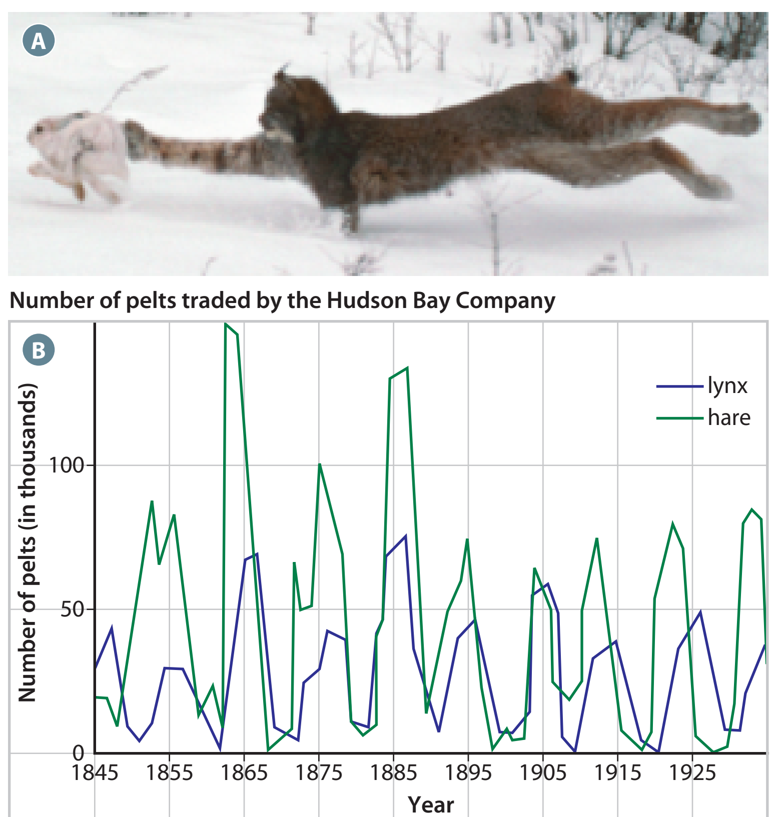


Figure 20.12 **(A)** The Canada lynx has strong forelimbs with sharp claws, which it uses to catch its main prey, the snowshoe hare. **(B)** Population estimates of snowshoe hare and Canada lynx show a pattern of 10-year cycles in population size. The hare population usually peaks about a year before the lynx population peaks.

BiologyFile

Try This
With a partner, take different sides to debate whether any of the following organisms should be classified as predators:
- plants that capture and digest insects
- animals that scavenge and eat dead animals but do not kill them
- herbivores, such as certain types of insects, that kill the plants they eat rather than just grazing on parts of the plants

led scientists to hypothesize that predator-prey interactions were causing the population cycles.

Another hypothesis to explain the cycling of snowshoe hares was that at higher population numbers, the hares were depleting their food supply. The reduction in the quantity and quality of the vegetation they browsed on therefore caused the snowshoe hare population to crash. An eight-year experiment to test the two hypotheses showed that snowshoe hare populations did, in fact, increase when more food was available to them. Test populations that were protected from predators increased, as well. With both abundant food and protection from predators, the snowshoe hare populations did even better. Based on these results, scientists have concluded that the periodic dips in snowshoe hare populations are probably due to a combination of food shortages and increased predation (Figure 20.13).

Predator-prey interactions also influence natural selection for adaptive traits. Individual lynx that are more successful hunters, for example, are more likely to survive and reproduce, and thus pass on their traits to the next generation. Snowshoe hares that are faster or better at hiding are also more likely to pass down their successful traits.

Effects of changes in food and predation levels on snowshoe hare populations

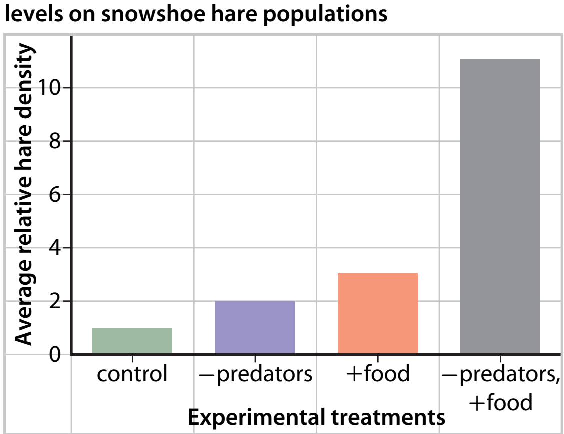


Figure 20.13 The results of a field experiment on snowshoe hare populations. Plots in which either the hares had unlimited food, or were safe from ground-dwelling predators, or both were compared to control plots, which were undisturbed sections of boreal forest.

Q 19 How do producer-consumer relationships put selective pressure on both partners?

Q 20 Describe two hypotheses to explain the population cycles of the snowshoe hare and the Canada lynx.

Defenses Against Consumers

Producers and consumers typically *co-evolve* as a result of their interactions. Many primary producers, for example, have adaptations that help to protect them from their consumers. Some plants, such as the milkweed plant (*Asclepias* sp.), produce bitter-tasting chemicals that discourage many herbivores—although some herbivores are able to adapt. Other plants, such as the cactus (family Cactaceae), have protective thorns, spines, or hairs. Some prey animals—the porcupine (*Erethizone dorsatum*), for instance—are similarly protected by their sharp quills. Many prey species are camouflaged, making them difficult for predators to find. For example, inchworm caterpillars (such as *Necophora quernaria*) and short-horned lizards (*Phyrnosoma hernandesi*) have different forms of cryptic coloration that allow them to blend in with their surroundings (Figure 20.14). By staying still, they may escape the detection of potential predators.

Cryptic coloration is a type of **protective coloration**, or body colour as a natural defense mechanism. In nature, black, yellow, and red are typical warning colours that predators come to associate with dangerous or unpalatable animals. The highly venomous eastern coral snake (*Micrurus fulvius fulvius*), for example, has red and black stripes. Some of the most poisonous frogs of South America are red or yellow. Stinging bees and yellowjacket wasps—members of the Hymenoptera order of insects—are black and yellow.

Figure 20.14 Cryptic coloration. **(A)** An inchworm caterpillar closely resembles the twig that it hangs from. **(B)** The short-horned lizard of North America lives in sparsely vegetated areas of mixed-grass prairie. The lizards blend in so well with their environment that researchers have difficulty finding and counting them.

The syrphid fly (family Syrphidae) has the distinctive warning coloration of a yellow-jacket wasp, but no stinger (Figure 20.15). Thus, the syrphid fly is said to be a mimic. It relies on looking like a well-defended model to deter predators. This form of mimicry is known as *Batesian mimicry*.

Two or more species that are poisonous, harmful, or unpalatable may also benefit by mimicking each other. For example, the monarch butterfly (*Danaus plexippus*) closely resembles its co-mimic, the viceroy butterfly (*Limenitis archippus*). While a caterpillar, the monarch feeds on milkweed leaves and stores the milkweed poison in its body for life. When a bird learns by trial and error that eating monarch butterflies makes it sick, it will avoid all butterflies that look like monarchs, including viceroy butterflies. Scientists hypothesize that the converse is also true: when a bird finds that viceroy butterflies are distasteful, it will avoid all butterflies that look like viceroys. This co-evolved defense mechanism is known as *Müllerian mimicry*.

21 The snowshoe hare is difficult to spot. During the winter it has a white coat, which it sheds in the spring for a brown coat that also provides camouflage. What is the name of this natural defense mechanism?

22 Explain the difference between Batesian and Müllerian mimicry.

Symbiotic Relationships

Populations that have lived in association for millions of years have often co-evolved to develop even closer relationships. The direct or close relationship between individuals of different species that live together is called **symbiosis**. Symbiotic relationships usually involve an organism that lives or feeds in or on another organism, sometimes called the *host*. Three forms of symbiosis are mutualism, commensalism, and parasitism.

Mutualism

When both partners in a symbiotic relationship benefit from the relationship, or depend on it in order to survive, their relationship is called **mutualism**. Lichen, for example, is actually a combination of an alga (or cyanobacterium species) and a fungus. In some cases, their mutualistic relationship allows them to grow on exposed, bare rock, where neither one would survive on its own. The algal partner photosynthesizes, which provides food for both organisms. The fungal

BiologyFile

Web Link

Various types of fish feed on guppies (*Poecilia reticulata*). Scientists have found that the number and types of predators in a stream influence the natural selection of guppies. Conduct an online simulation of evolution in guppy populations. In what ways do the populations change over time?

www.albertabiology.ca
WWW

Figure 20.15 Mimics, such as the syrphid fly, have evolved to look like harmful or unpalatable species as a defense mechanism against predators.

partner protects the alga from drying out or blowing away. As well, it produces an acid that dissolves rock, releasing minerals that are needed by the alga.

Animal behaviour is important in some cases of mutualism. In Latin America, for example, certain species of *Acacia* tree have a mutualistic relationship with stinging ants of the genus *Pseudomyrmex* (Figure 20.16). The leaves of the *Acacia* produce protein-containing structures and a sugary liquid, which the stinging ants consume. The stinging ants live, protected, inside the tree's hollow thorns. The ants benefit the tree by attacking any other herbivores that land on it and by providing organic nutrients. The ants also cut down the branches of other plants that come in contact with the *Acacia*, which ensures that the *Acacia* has adequate light for photosynthesis.

Commensalism

Commensalism is a symbiotic relationship in which one partner benefits and the other partner neither benefits nor is harmed. For example, a shark does not appear to benefit or suffer from its relationship with suckerfish (*Remora* sp.), which use their sucker-like dorsal fins to hold fast to the shark's body. The suckerfish, however, receive protection and bits of food from the shark.

It may be difficult to determine whether both partners benefit from a symbiotic relationship. Why do brown-headed cowbirds (*Molothrus ater*) spend so much time hovering around the hooves of grazing bison and domestic cattle (Figure 20.17)? Scientists have discovered that as the large animals walk through the grass, they flush out insects, which are eaten by the birds. The relationship between the cowbirds and the cattle appears to be an example of commensalism. The cowbirds, however, sometimes pick flies and other parasites from the cattle's skin, which benefits the cattle. Is this relationship really an example of mutualism? There are probably few true cases of commensalism. Both partners in symbiosis are usually affected in some way, although how they are affected may not be clear.

Figure 20.16 Stinging ants live in the hollow thorns of certain species of the *Acacia* tree in Latin America. The tree provides food for the ants in the form of a sweet nectar and proteins. The ants protect the tree from herbivores and, as shown here, from being shaded by other plants.

Figure 20.17 The brown-headed cowbird benefits from the insects that are flushed out of the grass by bison and domestic cattle as they graze. Is this an example of commensalism?

Parasitism

Mistletoes are a group of related plant families that live on trees and shrubs. Some mistletoes have flowers but no developed leaves, and obtain food by growing roots directly into the bark and phloem of conifer trees. The interaction weakens the trees and predisposes them to disease. This relationship is an example of **parasitism**, a form of symbiosis in which one partner, the parasite, benefits at the expense of its host.

Parasites are among the most successful species in the world—they thrive in most parts of the biosphere. Parasites include viruses and various types of worms, unicellular organisms, and insects. They affect almost all species of wild and domesticated plants and animals (Figure 20.18). Internal parasites usually depend on their interaction with their host to survive. Some internal parasites, such as the protist *Plasmodium falciparum* which causes malaria, have evolved unique survival strategies, such as wrapping themselves in their host's liver cell membranes, to escape detection by the host's immune system.

Parasites have a large impact on our global economy and quality of life. The World Health Organization estimates that over 1.4 billion people are infested with parasites. Malaria affects more than 500 million people and results in 2 to 3 million deaths annually. In Alberta, cold weather kills off some, but not all, potential parasites. Almost 3 percent of Albertans are affected by *Giardia* sp., a protozoan that invades the large intestine, causing diarrhea.

In nature, parasites are an important factor in limiting the growth of host populations. When individuals succumb to parasites, this may help the host population as a whole, because it reduces the density of the population and thus reduces competition for limited resources. In addition, weakened hosts may become prey for other animals. Why, however, do parasites not kill all their potential hosts? If the host population went extinct, then, presumably, so would its parasites. If a few hosts survive, the parasites will also survive.

23. Define symbiosis.
24. Give one example of mutualism, and explain how the partners in the relationship benefit.
25. Define commensalism.
26. Explain how parasitism is different from mutualism and commensalism.

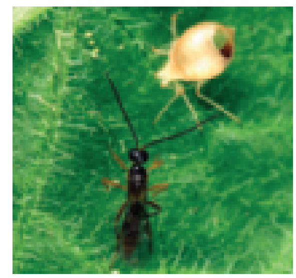
Succession: Community Change over Time

Following a forest fire, an area may appear barren. Within months, however, new vegetation may sprout, and then animals may repopulate the area. Years later, the same area will likely be thick with life. This process is known as **succession**, the sequence of invasion and replacement of species in an ecosystem over time. Succession is driven by both abiotic factors, such as climate, and biotic factors, such as interspecific competition for changing available resources.

BiologyFile

Web Link

Parasitoids, such as braconid wasps, are organisms that lay their eggs in the larvae of other insects, effectively killing the larvae. The wasp shown here has just emerged from a hole in the aphid's abdomen. Parasitoids can be used for the biological control of insect pests. How are parasitoids being used in Alberta?



www.albertabiology.ca
WWW

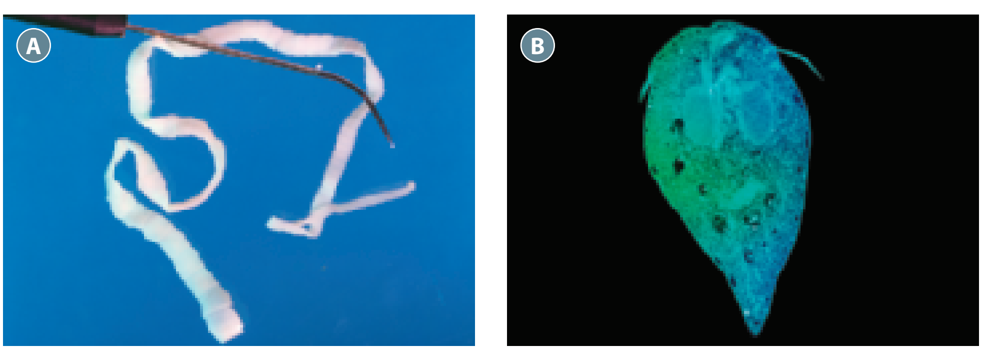


Figure 20.18 **(A)** Tapeworms (*Taenia* sp.) are transferred from livestock to humans when people eat infected and undercooked beef or pork. The adult tapeworm's tough cuticle protects it from the digestive enzymes in the small intestine, where it attaches and absorbs nutrients. A tapeworm can lay up to 10 000 eggs each day. The eggs, which are shed in infected individuals' feces, enter the environment where they can be picked up by another host. **(B)** *Giardia* sp. infections are sometimes referred to as beaver fever. A large outbreak in Banff, Alberta, in the 1980s may have resulted from infected beavers shedding *Giardia* sp. into the water supply in their feces. The contamination of drinking-water intake supplies with sewer water is the likely cause of other *Giardia* sp. outbreaks.

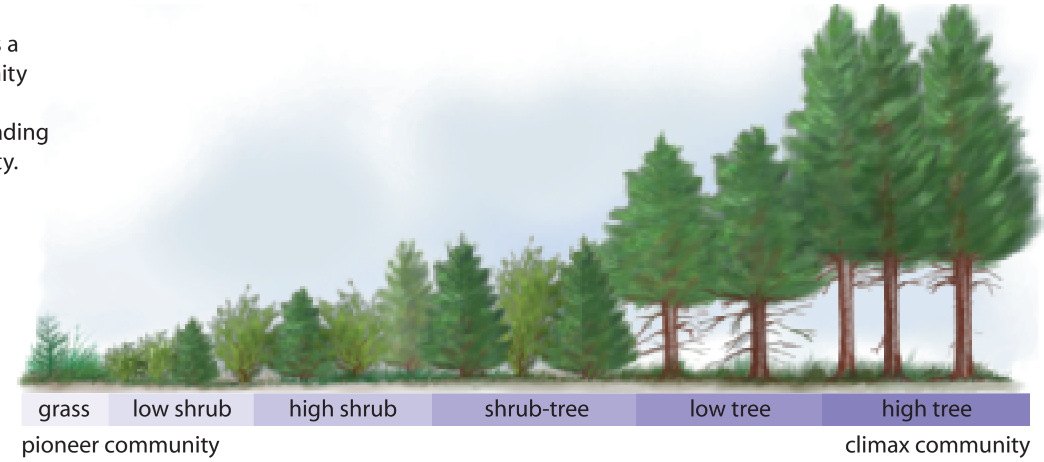


Figure 20.19 Succession is a gradual change in community structure, beginning with a pioneer community and leading towards a climax community.

Primary succession begins when there is no soil present, such as on bare rocks left behind by a retreating glacier or on a hardened lava bed. According to the classical model of succession, species populate an area in a specific chronological order (Figure 20.19). The first species to colonize an area and initiate succession form the **pioneer community**. The first species are organisms such as lichens that tend to be small and opportunistic, and able to grow in harsh conditions. Soil starts to form as some of these organisms die. As the soil builds up, its nutrient content, moisture content, and pH change (Figure 20.20). This allows larger species, such as mosses, to grow in the area. Grasses, annual herbs, shrubs, and trees follow, and the diversity of species expands (see Figure 20.21). The plants compete for light and living space. Due to interspecific competition and the changing habitat, some populations are better able to survive. These populations replace those that are not able to survive. Animals may join the community and, as the species of plants change, so do the species of animals. The latecomers in the process of succession form a **climax community**. This community may remain relatively stable if there are no major environmental changes.

Succession also occurs in microbial communities. As you may recall from Chapter 2, each type of micro-organism in a community plays a particular role. In Investigation 20.B, you will explore the process of microbial succession.

Disturbing Events

An event that changes the structure of a community—sometimes destroying all actively growing organisms—is called

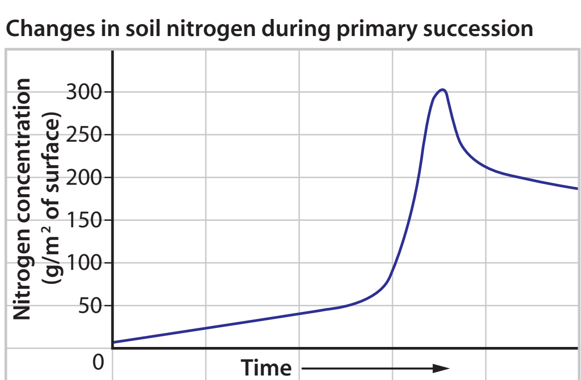


Figure 20.20 Nitrogen content of soil based on samples from Glacier Bay, Alaska. When primary succession begins, there is no soil and very few nutrients available to the organisms. As the organisms die and soil builds up, so do soil nutrients, such as nitrogen. Organisms from different species can then use the nutrients from the soil. They may also change the composition of the soil.

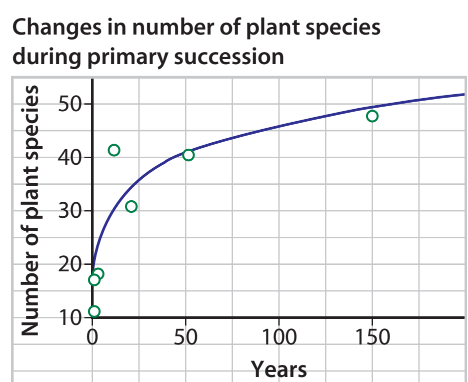


Figure 20.21 Plant succession in Glacier Bay, Alaska. By studying different sites where a glacier had retreated, ecologists found that plant diversity increased in the first 200 years of primary succession, and then levelled off.

INVESTIGATION 20.B

Target Skills

Designing and **performing** an experiment to demonstrate succession in a micro-environment

Designing and **performing** an experiment to demonstrate the effect of an environmental factor on population growth rates

Communicating ideas and results

Celebrate the Small Successions

Ducks are not the only inhabitants of the local pond. Protozoans, such as *Paramecium* sp., and microscopic algae may be found swimming in the water where oxygen is available. The oxygen-poor mud at the bottom of the pond likely contains methane-producing bacteria or sulfate-reducing bacteria. What happens to populations of these micro-organisms when they are contained in a micro-environment?

Questions

How can you demonstrate microbial succession over time using everyday materials? What factors influence succession in a microenvironment?

Safety Precautions

- To avoid creating completely anaerobic conditions in the jars and to prevent gases from building up in the jars, leave the lids on the jars loose.
- Do not leave the micro-environments near open flames. Gases that are produced in the micro-environments may ignite.
- Be careful not to smell the micro-environments or the bleach solution directly. Breathing in either hydrogen sulfide gas or chlorine gas is dangerous.
- Wash your hands after working with the micro-environments.

Materials

- container of 10 % bleach (for used microscope slides, cover slips, and pipettes)
- pond water (supplied by your teacher)
- wood shavings or dried grass
- paper towels
- pH paper
- microscope slides
- cover slips
- long plastic pipettes
- 2 mason jars with lids
- microscope
- laboratory fridge

Experimental Plan

1. Use Chapter 2 and library or Internet resources to refresh your memory about the role of micro-organisms in the carbon cycle.
2. Using the listed materials as a starting point, with your group, decide what environmental factor your group will manipulate. Will you examine the effect of temperature on succession in the micro-environments? Will you examine the effect of frequent aeration on succession in the micro-environments?
3. Decide exactly how you will set up each micro-environment. Also decide how and when you will observe the micro-environments. How will you detect changes in the microbial community? How will you detect population growth in a specific population?
4. Write a step-by-step procedure for your experiment. Be sure to include safety precautions in your procedure.
5. Once your group has agreed on the procedure, have your teacher approve it.

Data and Observations

Set up your micro-environments, and take your initial observations. Make periodic observations throughout the duration of the experiment.

Analysis

1. What environmental factor did you test?
2. How were you able to identify changes in the microbial community over time?

Conclusions

3. Describe how the microbial communities in each micro-environment changed over the course of the experiment. Which micro-organisms were most abundant at the beginning, middle, and end of the experiment? Which micro-organisms were least abundant at these three times?
4. What interspecific interactions might account for the succession of micro-organisms in the micro-environments?
5. How did the environmental factor that you tested affect the growth of particular populations in the micro-environments?
6. What abiotic factors might account for the succession of micro-organisms in the micro-environments?

BiologyFile

FYI
After grey wolves were re-introduced into Yellowstone National Park in the United States, the elk no longer frequented the banks of streams where they once grazed out in the open. Now that the elk graze elsewhere, the vegetation has grown back on the stream banks, slowing their erosion.

an **ecological disturbance**. **Secondary succession** is the recolonization of an area after an ecological disturbance, such as a forest fire or flood, or agricultural activity. The soil, which contains nutrients and organic matter, is not usually destroyed in an ecological disturbance. Seeds and the roots of vascular plants remain buried in the soil, as do the spores of ferns and mosses. In fact, some plant species produce seeds that will germinate only after they are exposed to the extreme heat of a forest fire. The giant sequoia (*Sequoiadendron giganteum*) of the Pacific Northwest and the lodgepole pine (*Pinus contorta*, the provincial tree of Alberta) are two examples. This adaptation ensures that there will be plenty of light and nutrients available for new seedlings.

Like primary succession, secondary succession includes changes in the composition and number of species over time. The stages of succession may occur over weeks in an area recovering from a flood. In other areas, such as a new forest, succession may continue for 150 years. According to the classical model of succession, once the climax community has developed, it will remain stable unless there is a major ecological disturbance.

Ecologists now think that ecological disturbances are the norm rather than the exception in many communities. Even a tree falling in a rain forest creates a small ecological disturbance. This, and larger disturbances, such as clear cutting a forest, open a space in the canopy, allowing light to hit the ground and secondary succession to occur. Thus, ecological disturbances are important for many plants. Research shows that the magnitude of a disturbance affects the types of organisms that will inhabit an area. Spruce (*Picea* sp.), a shade-tolerant plant, does well following a small ecological disturbance in a forest. A large disturbance in a forest provides plenty of light and allows shade-intolerant plants, such as the lodgepole pine, to flourish. Ecological disturbances are also important for animals. The berry bushes that grow up a few years after a forest fire are an important food for grizzly bears as they gain body mass in preparation for hibernation.

Ecologists must therefore consider how ecological disturbances affect different species when trying to establish—or preserve—healthy natural communities. Understanding the role of ecological disturbances in structuring communities is currently an important area of investigation in ecology.

BiologyFile

Web Link
One of the first plant species to colonize disturbed forested areas, such as those razed by a fire, is *Epilobium angustifolium*, commonly called fireweed or willowherb. This plant is found throughout Canada. What are some traditional uses of this plant by First Nations?

www.albertabiology.ca
WWW

27 What is succession?

28 Distinguish between
a) primary succession and secondary succession
b) pioneer community and climax community

Section 20.2 Summary

- Population dynamics refers to changes that occur in a population over time, such as population growth.
- Population dynamics are influenced by biotic and abiotic factors.
- Density-dependent limiting factors on population growth include disease and intraspecific competition for limited resources, such as food, living space, and light.
- Interspecific competition is the competition among members of different populations for limited resources.
- Producer-consumer interactions may impact the growth of both the producer population and the consumer population, since the consumer population depends on the producer population for survival. Also, the consumer population may deplete the producer population.
- A predator is a consumer that kills and consumes other organisms, known as prey.

Thought Lab 20.3 Testing the Classical Model of Succession

Target Skills

Explaining changes in communities over time, using models of succession

On average, fires in the boreal forest of Alberta occur every 50 years. The life span of a lodgepole pine is 220 years. Many lodgepole pines do not have a chance to live to "old age" because of the frequency of these fires.

The classical model of succession came out of an explorer's observations of a glacial valley in the late 1800s. Because succession is such a long process, however, early ecologists had difficulty testing this model of succession. In fact, no studies have lasted the hundreds of years required to observe the entire life cycle of certain types of trees. Nevertheless, with the development of new technologies and long-term studies of model forests, ecologists are able to gather and assess new information.

Suppose that you are studying the impact of a wild land fire in an area of Alberta's boreal forest. All the above-ground vegetation in the area was destroyed. Suppose that you visit the area 20 years after the fire and see a layer of small white spruce trees growing below a layer of tall lodgepole pines. You hypothesize that this community is following the classical model of succession. If your hypothesis is correct, then presumably the pine trees are being replaced by the spruce trees, which are characteristic of climax communities in this area.

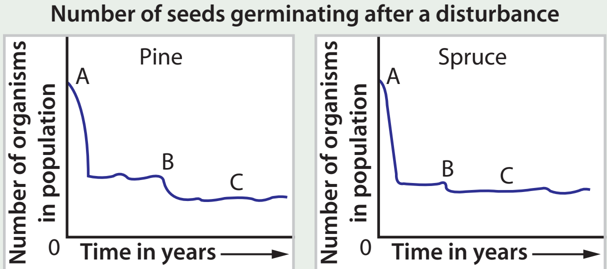
Procedure

Use the information above to answer the following Analysis questions.

Analysis

1. What type of succession—primary or secondary—is taking place in the area? Explain your answer.
2. You hypothesized that the community is following the classical model of succession, with one species replacing another. If your hypothesis is correct, what would you predict about the ages of the pine trees relative to the spruce trees? Explain your answer.
3. How could you determine the ages of the trees in the area?
4. Analysis of the trees in the area indicates that both populations are about 20 years old. How does this information affect your original hypothesis?
5. Scientists have studied the birth rate and death rate of each species of tree. They have used their data to create the following survivorship curves, which show the proportion of individuals in a population that survive over time.

Number of seeds germinating after a disturbance



As shown in section A on the graphs, both populations have a great decline in numbers after the seeds started germinating. List three factors that might cause the young seedlings to die.

6. Compare the rate of death of lodgepole pine trees with the rate of death of spruce trees in section A of the graphs.
7. Section B of the graphs represents a natural process called density thinning. It occurs in dense populations, when resources are very limited. Some of the population dies, which leaves more resources for the remaining population. Suggest a reason why density thinning affects the lodgepole pine population more than the spruce population.
8. Lodgepole pines are shade intolerant. When their seeds germinate, the seedlings grow very tall very quickly. In contrast, spruce trees are shade tolerant and grow more slowly than lodgepole pines. Would you expect the taller or shorter lodgepole pines to die during density thinning? Explain your answer.
9. Consider again your hypothesis that the community is following the classical model of succession and, therefore, the spruce trees are replacing the lodgepole pine trees. Based on your hypothesis, sketch a graph of the number of individual trees in each population versus time. Compare your graph to the survivorship curves. Formulate an alternative hypothesis about how succession is occurring in the community under study.
10. Which type of competition—interspecific or intraspecific—is more important to the pattern of succession in the study area? Explain your answer.

Extensions

11. Explain how the trees came to grow in the study area in the first place.
12. Some plants need more light than others to survive. Knowing this, explain how the following factors might affect the type of plants that will start the process of secondary succession after an ecological disturbance. Then identify the factor that is probably the most important in determining which species will be the first to repopulate an area after an ecological disturbance. Explain your reasoning.
    a) the type of ecological disturbance (for example, a forest fire versus a fallen tree)
    b) the types of seeds left in the soil after the disturbance
    c) the availability of moisture in the soil
    d) the availability of nutrients in the soil

- With natural selection for more successful producers and more successful consumers, producers and their consumers co-evolve.
- Producer defenses against consumers include toxin production and protective coloration, such as cryptic coloration and mimicry.
- Co-evolution may result in symbiosis—the close or direct association of individuals of separate species.
- Symbiosis in which both partners benefit is called mutualism. Symbiosis in which one partner benefits and the other partner does not benefit nor is harmed is called commensalism. This form of symbiosis is probably rare, however.
- Symbiosis in which an organism benefits at the expense of the host that it lives with is considered parasitism.
- An ecological community is comprised of interacting populations.
- A new community may form in an area, resulting in a sequence of invasion and replacement of species known as succession.
- Primary succession begins on bare rock or hardened lava with the formation of a pioneer community.
- Secondary succession occurs where there has been an ecological disturbance, such as a forest fire or a fallen tree, in a previously existing community.
- A climax community is a theoretical end point late in the process of succession.

Section 20.2 Review

1. White spruce (*Picea glauca*) may compete with lodgepole pine (*Pinus contorta*) for light and living space. Eventually, the white spruce may take over. What kind of competition is taking place? Provide two reasons why the white spruce may out-compete the lodgepole pine.

2. Many species have developed specific coloration that protects them from predators.

a) Explain the relationship between warning coloration and Batesian mimicry.

b) Why might it be important for the mimic to learn how to mimic the behaviour of its model?

c) Predict what would happen to the population of a mimic species if its model species were eliminated from the area? Justify your prediction.

3. Explain the role of natural selection in intraspecific competition.

4. Identify the symbiotic relationship demonstrated in each of the following situations:

a) Tapeworms live in the small intestine of animals, including humans, and absorb the available nutrients. They lay about 10 000 eggs a day. In extreme cases, tapeworms have been known to reach a length of 30 m.

b) Some members of the orchid family grow on the branches of trees where they receive plenty of light. They absorb all their necessary nutrients directly from the atmosphere.

c) Some coral reef fish and shrimp obtain energy by eating parasites from the scales and gills of larger fish. These “cleaners” are suitable prey for the larger fish, but they are not eaten.

d) Nitrogen-fixing bacteria receive protection and nutrients from their host plant. In return, they provide their host with nitrogen compounds in a form that their host can use.

5. Define succession, and describe its importance to community dynamics.

6. Envision a neighbourhood where no one has touched a front lawn in 10 years. Describe any changes that you think might have occurred over the 10 years. What do the lawns now look like? What do you see in the neighbourhood?

SECTION 20.3

Sharing the Biosphere

Section Outcomes

In this section, you will
- **explain** why Canadian society supports research and activities to achieve sustainability
- **evaluate** and **summarize** the role of an interspecific relationship in the deliberate introduction of a species for biological control, and **present** a position on the issue
- **analyze** data on human population growth rates in various countries
- **predict** Earth's carrying capacity, and **justify** your position

Key Terms

sustainability
age pyramid

You have learned how genetic changes are passed from one generation to the next and how genetic changes affect future populations. You have also learned that ecological communities are in constant flux and that organisms and the non-living environment change in response to each other.

How, then, do we know when there is too much change—in individual organisms, in natural populations and communities, or in the abiotic environment? How can we reach consensus about the amount of change that is acceptable? Even when we reach consensus on one of these issues, what is the most effective way to act? In this section, you will consider the role of *Homo sapiens*—you—in the biosphere.

Assessing the Significance of Population Changes

For many Canadian Inuit, the polar bear (*Ursus maritimus*) is a vital resource. When Inuit hunters kill a polar bear, they share the meat with their families and with other members of their community. The skin and fur are used to make their traditional cold-weather clothing. The Inuit greatly respect the intelligence and hunting skills of *Nanuq* (Inuktitut for "polar bear"), which is a top predator in Arctic food webs. A decline in polar bear populations would mean significant changes to the traditional Inuit way of life, as well as to the Arctic ecosystem.

Polar bear counts indicate that the polar bear population of M'Clintock Channel in Nunavut is less than half of what it was in the 1970s. On the other hand, people living near Hudson Bay are encountering polar bears more often than they did in the past—so much so that people are concerned for their safety. One explanation for the observed increase is that the polar bears are emigrating from areas where the sea ice has become too thin to live on. Conversely, the M'Clintock Channel population could be losing bears to emigration. Over-hunting (including sport hunting) during the last century may have also contributed to the population's decline. Many scientists predict that, overall, polar bear populations will decrease as the melting pattern of Arctic sea ice changes. Other threats to polar bear populations may include the increased presence of snowmobiles, aircraft, and construction projects (such as the construction of radar stations), as well as the contamination of polar bear prey by environmental pollutants.

Given the threats faced by polar bear populations, many people wish to act to limit these threats. Deciding *how* to act is complicated, requiring input from various stakeholders in order to establish a course of action.

Establishing a Course of Action

At the end of Unit 1 you read about **sustainability**—the concept of living in a way that meets our needs without compromising the health of future generations or the health of the planet. For people who hunt or grow their own food, the connections between society, the economy, and the environment may be easier to see. Even for city dwellers, however, the practice of sustainability includes all three elements.

The most effective way to practise sustainability is not always clear. Separate lines of scientific evidence can help us make decisions. Even so, as you will discover in Thought Lab 20.4, careful consideration is needed to sort out, organize, analyze, interpret, and evaluate the evidence.

Q 29 Define sustainability.

Thought Lab 20.4 Biological Control or Damage Control?

Target Skills

Summarizing and **evaluating** an interspecific relationship

Developing, **presenting**, and **defending** a position on whether organisms should be deliberately introduced into a new environment

The cassava plant (*Manihot esculenta*) was introduced to Africa in the sixteenth century. Today, it is a dietary staple in many African countries. Around 1970, the cassava mealybug (*Phenacoccus manihoti*) was unintentionally introduced into Western Africa. It had no natural predators on the continent and, by 1973, was devastating cassava crops. Within a decade, researchers discovered a tiny wasp from Paraguay whose larvae specifically parasitized the cassava mealybug. The wasp, *Epidinocarsis lopezi*, was introduced into the cassava growing regions of Africa and soon brought cassava mealybug infestations under control.

Procedure

Your group will be assigned one example of biological control from the table. Use the information in the table to answer the Analysis questions that follow. You may wish to do further research. Your group will then present your findings to the class, using appropriate visual aids.

Analysis

1. Describe the interaction between the biological control agent you are studying and its target species.
2. Describe the benefits and disadvantages of introducing this biological control agent to new environments.
3. Present and justify your position on whether or not this biological control agent should be used to control invasive or pest species.
4. After all the presentations, compare the different examples of biological control to determine why some had successful outcomes and some did not.

Examples of Biological Control Using Introduced Species

Location of introduction	Invasive or pest species	Species introduced for biological control	Relationship between invasive or pest species and biological control agent	Outcomes of biological control
Australia	sugar-cane pests from the Scarabaeidae beetle family	cane toad (*Bufo marinus*)	Predatory: It was believed that the cane toads would eat the sugar cane beetles.	The cane toads have had little to no effect on the sugar cane beetles because the toads and beetles do not come in contact with each other very often. The toads are extremely invasive. They are poisonous and are a danger to children, pets, and wild animals that eat them. As well, they prey on many native animal species, including snakes.
Canada, United States of America	cabbage seedpod weevil (*Ceutorhynchus obstrictus*), which damages canola and other *Brassica* species	two species of wasp (*Microctonus melanopus* and *Trichomalis perfectus*)	Parasitic: *M. melanopus* attacks adult weevils and *T. perfectus* attacks weevil larvae.	The parasitic wasps have successfully suppressed cabbage seedpod weevil populations in Europe, but so far have had only limited success in North America.
Canada, United States of America	musk thistle (*Carduus nutans*), an introduced plant that is a noxious weed in North America	seed-head weevil (*Rhinocyllus conicus*)	Parasitic: The weevils lay eggs on the buds of thistle plants, and the larvae feed on the plants and prevent the development of new seeds.	The weevils are now well-established in North America and have greatly helped to reduce musk thistle populations. The weevils also attack *Cirsium canescens*, a thistle that is native to North America, and have reduced populations of these thistles in the Nebraska sandhills of the United States.
United States of America (Hawaii)	southern green stinkbug (*Nezara viridula*), an introduced pest that damages macadamia-nut trees	species of the *Trichopoda* fly and the *Trissolcus basalis* wasp	Parasitic: The flies lay eggs on adult stinkbugs. The fly maggots then penetrate and eat the stinkbugs. The wasps deposit their eggs inside stinkbug eggs, where the wasp larvae develop.	Introducing the flies and wasps has helped to control the invasive stinkbugs, but may have contributed to the decline of the native koa bugs (*Coleotichus blackburniae*).

Growth of the Human Population

The human population is currently in a state of exponential growth. How close is the human population to reaching its carrying capacity? Species with typical *r*-selected strategies, such as some insects, often have boom or bust population cycles. In comparison, species with typical *K*-selected strategies have populations that grow exponentially for a while, and then fluctuate in size close to the carrying capacity of their habitat. Humans have many *K*-selected life strategies, such as long life spans, a relatively low reproductive rate, and parental care of their young. How is the human population affected by density-dependent limiting factors? How might intraspecific competition and disease affect the human population? What will happen to the human population as resources become scarce?

Determining the exact number of people in early times is not an easy task. Estimates made before 1650 are crude. However, demographers (people who study populations) generally think that the human population remained fairly stable until the beginning of the Industrial Revolution, with one exception. During the fourteenth century, a bacterial infection known as the Black Death killed millions of people (Figure 20.22).

From the mid-eighteenth century on, living conditions for many people began to improve. As new understandings about hygiene were put into practice, and medical and agricultural technologies were developed and refined, the death rate slowed and the rate of population growth accelerated immensely. Recall that an exponentially growing population grows faster as it gets larger. As Figure 20.22 shows, it took 130 years for the global human population to grow from 1 billion (in 1800) to 2 billion individuals (in 1930). It took only 12 years, however, for the population to increase from 5 billion (in 1987) to 6 billion (in 1999).

The growth rate has not been the same for all human populations. Britain, Japan, and more industrialized countries in Europe and North America were the first to experience a drop in death rate, especially among infants and children. As a result, after a few generations, people in these countries began to have fewer children, and the birth rate of these populations dropped. Less industrialized nations in Africa, Asia, and Latin America began to move through the same stages in the twentieth century. Human population growth rates are still changing in the twenty-first century. In Thought Lab 20.5, you will explore this idea by comparing population growth in different countries.

Population Age Structure

As the growth curves you made in Thought Lab 20.5 show, the population growth rates (*gr*) in some countries are slowing down. Keep in mind that just because a population's growth rate is slowing, this does not mean that the population is shrinking. A positive,

BiologyFile

FYI
In 1918, an outbreak of a highly lethal strain of influenza (dubbed the Spanish Flu) claimed the lives of an estimated 2.5–5 percent of the global population. The virus killed adults mainly between 20 and 40 years of age. In the first 25 weeks of this global pandemic, up to 25 million lives were lost. Conservative estimates place the total number killed at about 50 million.

Estimated global population 5000 B.C.E–2000 C.E.

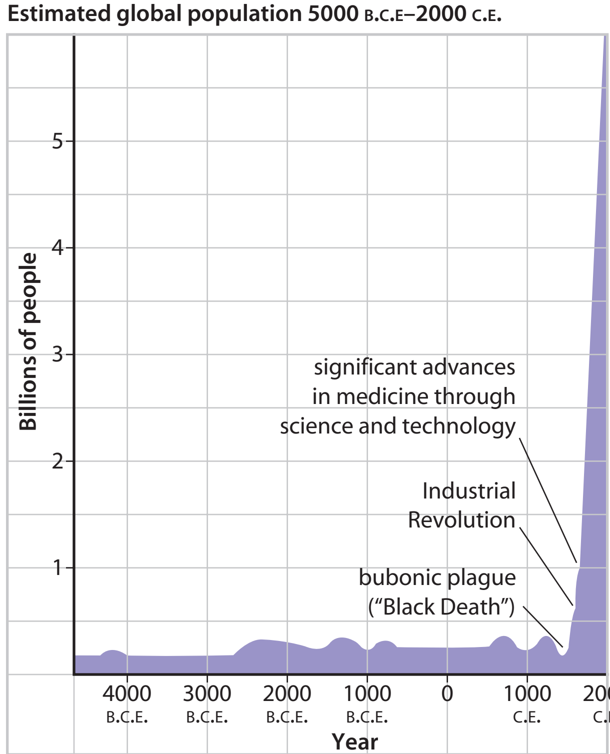


Figure 20.22 For most of its history, the human population has been stable or has grown very slowly. Explosive growth began after the Industrial Revolution in the eighteenth century, when the death rate in more industrialized countries dropped dramatically. The growth rate accelerated even more after World War II (1939–1945).

Thought Lab 20.5 Population Growth Rates in Different Countries

Target Skills

Comparing and **assessing** the growth rates of human populations in various countries

Although people may not have unlimited resources, many human populations appear to be growing exponentially. Since human populations in different parts of the world live in different environments, where people have different degrees of access to food, clean water, technologies, and medical aid, their per capita birth rates and death rates—and thus their growth rates—also vary. In this activity, you will compare the growth rates for several different human populations to see the effect of population growth rates on the shape of the growth curves.

Procedure

Use the table below to answer the following Analysis questions.

Human Demographic Information for Selected Countries in 2001

Country	Population size (millions) (*N*)	Number of births (*b*) per 1000 individuals	Number of deaths (*d*) per 1000 individuals
Canada	32.2	10	7
Ethiopia	77.4	41	16
Finland	5.2	11	9
Germany	82.5	9	10
Greece	11.1	9	10
India	1103.6	25	8
Nigeria	131.5	43	19

Source: 2005 World Population Data Sheet of the Population Reference Bureau

Analysis

1. Create a data table or computer spreadsheet with the following headings:

Predicted Population Growth from 2001 to 2011 in Selected Countries

Country	Annual per capita growth rate (*cgr*)	Population size (*N*) at one-year intervals										
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011

2. The table of demographic information on this page shows the total population size and the number of births and deaths that occur annually per 1000 people in different populations. In other words, the table shows birth and death *rates* for each population. Subtract the deaths per 1000 individuals from the births per 1000 individuals each year to calculate the annual per capita growth rate (*cgr*) for each population:
$$cgr = \frac{b}{1000} - \frac{d}{1000}$$
Note that this estimate of *cgr* does not take into account emigration or immigration.

3. Use Canada's 2001 population size and annual *cgr* to calculate the predicted population size for 2002:
$$N_{(\text{Canada in 2002})} = N_{(\text{Canada in 2001})} + (cgr)(N_{(\text{Canada in 2001})})$$
$$= (1 + cgr)(N_{(\text{Canada in 2001})})$$
$$= (1 + cgr)(32.2 \times 10^6)$$
Then use Canada's 2002 population size and annual *cgr* to calculate the predicted population size for 2003. Repeat this step for the rest of the years listed in your data table.

4. Repeat the calculations in step 3 for each country listed in your data table.

5. Using a full sheet of arithmetic graph paper (or a computer graphing program), graph the size of Canada's population from 2001 through 2011. This graph is a hypothetical population growth curve for Canada for 2001 through 2011. Remember to label each axis and include a title for your graph.

6. Graph population growth curves for the six other countries listed in your data table. You can use the same piece of graph paper (or plot area) for all the growth curves, as long as you use a different symbol or colour for each growth curve and provide a legend.

7. Compare the steepness of the different growth curves. Describe how annual *cgr* affects the steepness of a growth curve.

8. Describe the effect of a population's initial size on the steepness of its growth curve.

9. Why is the annual *cgr* negative for some populations? Describe the growth curve for a population with a negative *cgr*.

10. Based on your graph, which populations are currently undergoing exponential growth?

11. Based on your graph, for which populations is the growth rate (*gr*) slowing? (Recall that $gr = \frac{\Delta N}{\Delta t}$.)

12. Classify the countries in your data table into countries that you would consider to be more industrialized and countries that you would consider to be less industrialized. Compare the growth curves that are typical of each group. Explain the differences between the two types of curves.

though slower, growth rate means that a population will still grow, just not as quickly as it used to. You have also seen that per capita growth rates (*cgr*) vary among countries. What factors account for these differences?

Age pyramids are tools that demographers use to help them assess a population's potential for growth (Figure 20.24). An age pyramid shows the percent of males (on the left) and the percent of females (on the right) in different age categories (usually five-year intervals). Thus, an age pyramid can be used to see the proportion of a population in each of the following three stages of development: the pre-reproductive stage (0 to 14 years), the reproductive stage (14 to 44 years), and the post-reproductive stage (45 years and older).

An upright triangle-shaped age pyramid indicates that there are more births than deaths in the population, and that the population is therefore growing rapidly. The age pyramid for the Democratic Republic of Congo, for example, shows that the population was growing rapidly in 2000 (Figure 20.23). Because a large proportion of this population is young, the population will increase substantially when the current youth reach their reproductive years and have children of their own.

A rectangle-shaped pyramid represents a stable population. As you can see in the age pyramid for Sweden in 2000, a stable population has roughly the same proportion of people in each stage of development, with the number of births roughly equal to the number of deaths. An inverted triangle-shaped pyramid indicates that the population is declining, as in Germany in 2000.

Q30 What is an age pyramid?

Q31 Describe the structure of an age pyramid.

What Does Our Future Hold?

Given that age structure is a key predictor of a population's potential for growth, what are the implications for the global human population? The global human population doubled in the last half of the twentieth century. Most likely, this will not happen again over the course of a human life span. The twenty-first century will mark the first time that the elderly will out number the youth of the world. The global birth rate is expected to fall from 2.1 percent to 1.1 percent—the first time that it will drop because people are choosing to

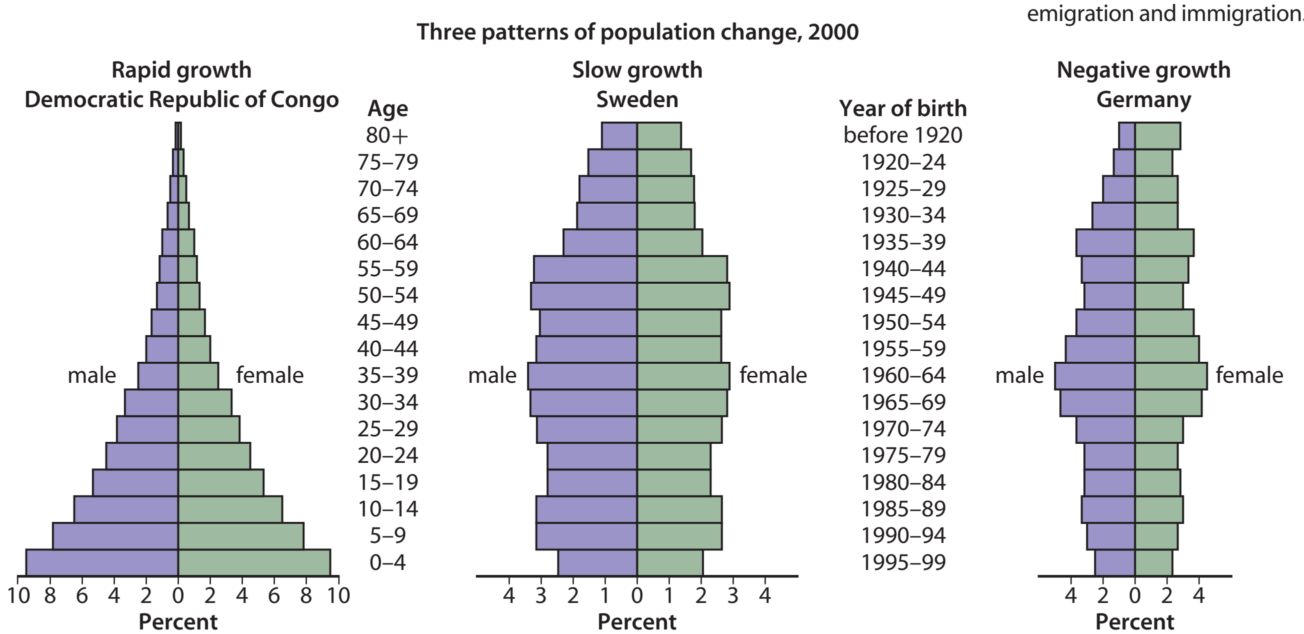


Figure 20.23 Age pyramids for the Democratic Republic of Congo, Sweden, and Germany in 2000. Predicted per capita growth rates based on age pyramids do not take into account emigration and immigration.

BiologyFile

Web Link
How quickly is the global population growing? Check out a world population clock on the Internet. On average, by how much does the global population increase in one day? How about in one minute?

www.albertabiology.ca
WWW

have fewer children. The high prevalence of HIV/AIDS in some populations means that fewer children are living to adulthood and more adults are dying at a younger age, which will decrease the growth rate of these populations.

Furthermore, in the twenty-first century, the number of people living in urban areas will outnumber the number of people living in rural areas for the first time. How will this affect Earth's carrying capacity?

Based on population growth rates and age structures, the state of the environment, and possible technological developments, many demographers predict that the global human population will level off at 9 billion, although estimates range from 7 billion to 14 billion (Figure 20.24).

Earth's Carrying Capacity

Advances in construction, medicine, sanitation, and agriculture have increased Earth's carrying capacity for the human population. In addition, some forms of biotechnology have improved crop yields, without taking up more space. Even so, scientists estimate that the world produces enough food to feed 10 billion people a vegetarian diet. Not all people are vegetarians, however. Furthermore, cities will have to expand to accommodate people moving from rural areas, and this may reduce the amount of land that is available for agriculture.

Human population growth projections to 3000 C.E.

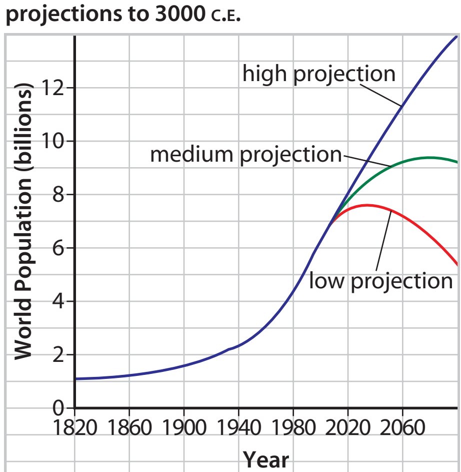


Figure 20.24 In 2005, the per capita growth rate of the global human population was 0.012. Many demographers predict that the population of the world will stabilize at 9 billion people, but not all agree. Depending on how other demographers interpret variables such as birth rate and death rate, predictions vary, as shown in this graph.

To estimate Earth's carrying capacity, many things must be considered. Like the International Space Station, Earth is a closed system. As well as needing resources, we will need effective ways to deal with garbage, sewage, and air pollution. How will the environment be affected by increasing amounts of waste and pollutants entering waterways from larger, denser populations? Will levels of carbon dioxide continue to rise, or will new technologies and habits help us limit the use of fossil fuels? Will countries share their resources to reduce poverty and combat disease? As the density of the human population increases, will we be more susceptible to pandemics, such as influenza?

Perhaps there are too many unanswered questions to be able to determine what the carrying capacity of the world actually is, and whether or not this carrying capacity has been reached. Most likely, different regions will have different limits to growth. No population—human or non-human—can act in isolation, however. We all share, and are connected to, the same biosphere.

Section 20.3 Summary

- Populations and the ecological communities they comprise change over time as a result of natural causes and human activities.
- Climate change, over-harvesting, pollution, and the introduction of invasive species can greatly affect populations.
- Sustainability is the concept of living in a way that meets our needs without compromising the ability of future generations to meet their needs or the health of the biosphere. The practice of

sustainability includes social, economic, and environmental considerations.

- For most of human history, the global human population was stable. Since the Industrial Revolution, improved living conditions have resulted in longer life expectancies and decreased infant mortality. The global human population has grown exponentially as a result.
- Different human populations have different age structures, as shown by age pyramids. Populations with more youth than older people are expected to grow more quickly than populations with fewer youth than older people, or the same number of youth and older people.
- Because people are having fewer children than they used to, the rate of growth in human populations is no longer exponential. Some populations are still growing, however.
- In 2005, the global human population was over 6 billion.
- The carrying capacity of Earth for the human population will be influenced by many factors. Demographers predict that Earth may be able to support from 7 to 14 billion people.

Section 20.3 Review

1. What limiting factor, in your opinion, will have the most influence on slowing down the population growth of the world? Justify your choice.

2. In 2005, the population of Brazil was 184.7 million. The population of Turkey was 72.9 million. If both countries have a per capita growth rate of 1.4 percent, which country would experience the largest impact from a reduction in *cgr*? Justify your answer.

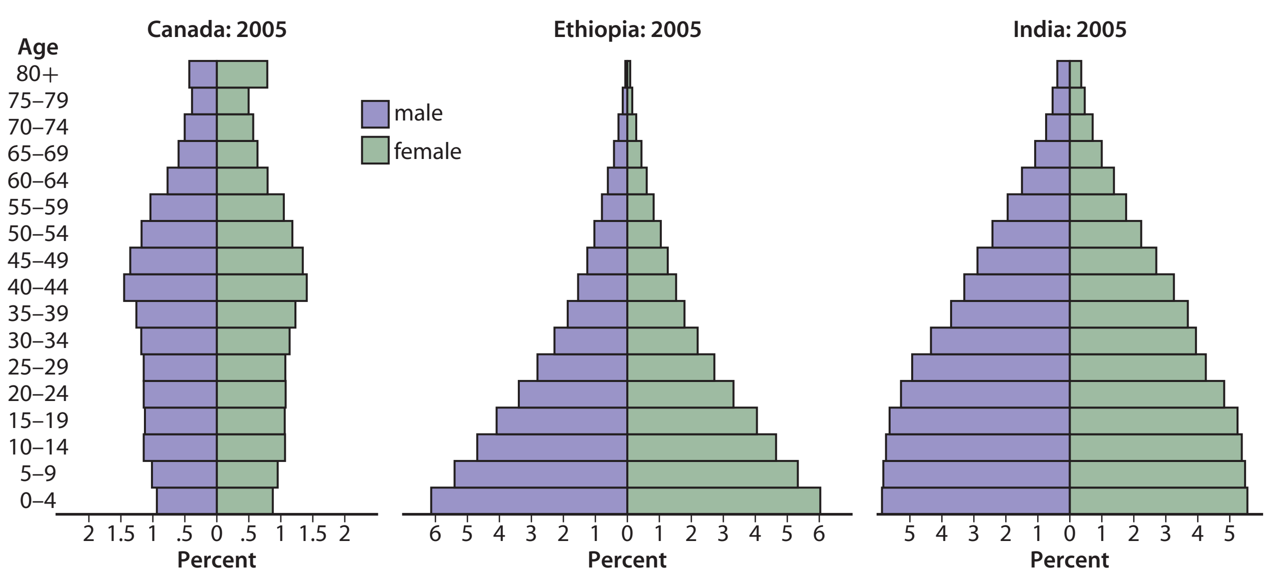
3. Explain why the global human population may be more susceptible to a pandemic, such as avian flu, as the population increases in size.

4. Examine the age pyramids shown below.

a) Describe the shape of the age pyramid for each country.

b) For each country, which would be greater—the birth rate or the death rate? Explain your answer.

c) Explain how the age structure of each population would affect the population's size over time.



Helping Hippos and Humans

For decades, humans and hippos had been on a collision course along a stretch of the Black Volta River in the Wechiau Traditional Area in Ghana, West Africa. Hippos had long used the winding river system as a place to raise their young, but their grazing grounds had been eroded and depleted as humans encroached upon the banks of the river with farming and fishing. As well, humans were killing hippos, either for the meat or because the hippos were wrecking fishing nets or canoes. The solution to the problem had less to do with technology than with Wechiau residents changing the way they thought about and interacted with their natural environment. They discovered that by accommodating the needs of the hippos and respecting the hippos' habitat, they would be helping to safeguard their own future.

Community-Run Conservation

The Wechiau area along the Black Volta River is home to the second largest hippo population in Ghana. In the early 1990s, the Ghanaian government proposed that a national reserve should be set up to protect the Wechiau hippos. The traditional authority, the local governing body in the area, rejected this idea. They feared that a national reserve, run from outside the community, would alienate their people from the land. Following talks between Wechiau chiefs and sub-chiefs of the traditional authority and representatives from the Nature Conservation Research Centre (a Ghanaian non-governmental organization that manages ecological projects in Ghana), an agreement was made to establish a hippo sanctuary.

According to the agreement, the sanctuary would be community-owned and operated and would encourage *ecotourism*, which incorporates the practice of sustainability into tourism. Profits would flow back to the villages in the area. Wechiau residents would learn about the importance of biodiversity and how biodiversity relates to their own survival. In early 1999, the year the sanctuary was established, the chief of Wechiau and his elders set up a buffer zone between the hippos and humans by declaring that all human activities other than fishing were prohibited within 2 km of the river along the length of the sanctuary area.

Saving Hippos, Sustaining Humans

The Wechiau Community Hippo Sanctuary (WCHS) is unique for several reasons. It is a community initiative with no central government involvement. It protects about 24 hippos, as well as other wildlife, in a core 40 km^2 area along the Black Volta River. Initially, the sanctuary was completely funded through subsidies and financial support from organizations such as the Calgary Zoo's Conservation Outreach Department. Starting in 2004, however, monthly tourist revenue has paid all operating costs, including local staff salaries and maintenance costs for overnight tourist lodges and a visitors' centre. Proceeds from the WCHS have also significantly benefited the 22 villages in the surrounding area, helping to pay the costs of building new schools and drilling new boreholes for fresh drinking water. Although many Wechiau residents continue to struggle daily to survive, they are committed to the vision of even greater long-term benefits with sustainability. The WCHS has been so successful that other communities in Ghana are looking to it as a model for protecting their endangered species.

• • •

1. Working toward long-term sustainability is not just about protecting the environment. It is also about balancing economic, social, and environmental goals. What are some of the goals that the WCHS helps people meet?
2. Recognizing the legitimacy of the local traditional authority in Wechiau has been the key to the sanctuary's success so far. What are the advantages of involving local communities in conservation projects, instead of handing habitats over to private companies or state governments?
3. The Calgary Zoo continues to support the WCHS in many ways, including providing an on-site wildlife education consultant, who helps to facilitate the sanctuary's progress. What other international conservation projects is the zoo involved in? Why is the zoo's work important to Canadians?

Chapter 20 SUMMARY

Population density is defined as the number of individuals living in a given area or volume over a specific time frame: $D_p = \frac{N}{A}$ or $D_p = \frac{N}{V}$. Interspecific and intraspecific interactions, as well as the distribution of resources within a habitat influence how individuals are dispersed within it. Three theoretical distribution patterns of individuals within a habitat are random, uniform, and clumped.

Four major processes that cause changes in population size are the number of births, immigration, the number of deaths, and emigration: $\Delta N = (b + i) - (d + e)$. The rate at which the size of a population changes over a given time interval can be described using the growth rate equation: $gr = \frac{\Delta N}{\Delta t}$. Per capita growth rate (*cgr*) describes the change in the number of individuals of a population over a given time interval in terms of rate of change per individual: $cgr = \frac{\Delta N}{N}$ or $cgr = \frac{N_{\text{final}} - N}{N}$.

Environmental resistance limits the birth rate or increases the death rate in a population. Given unlimited resources and ideal living conditions, the highest possible *cgr* for a population is its biotic potential (r). The carrying capacity (K) of a habitat is the maximum number of individuals that the habitat can support due to density-dependent limiting factors.

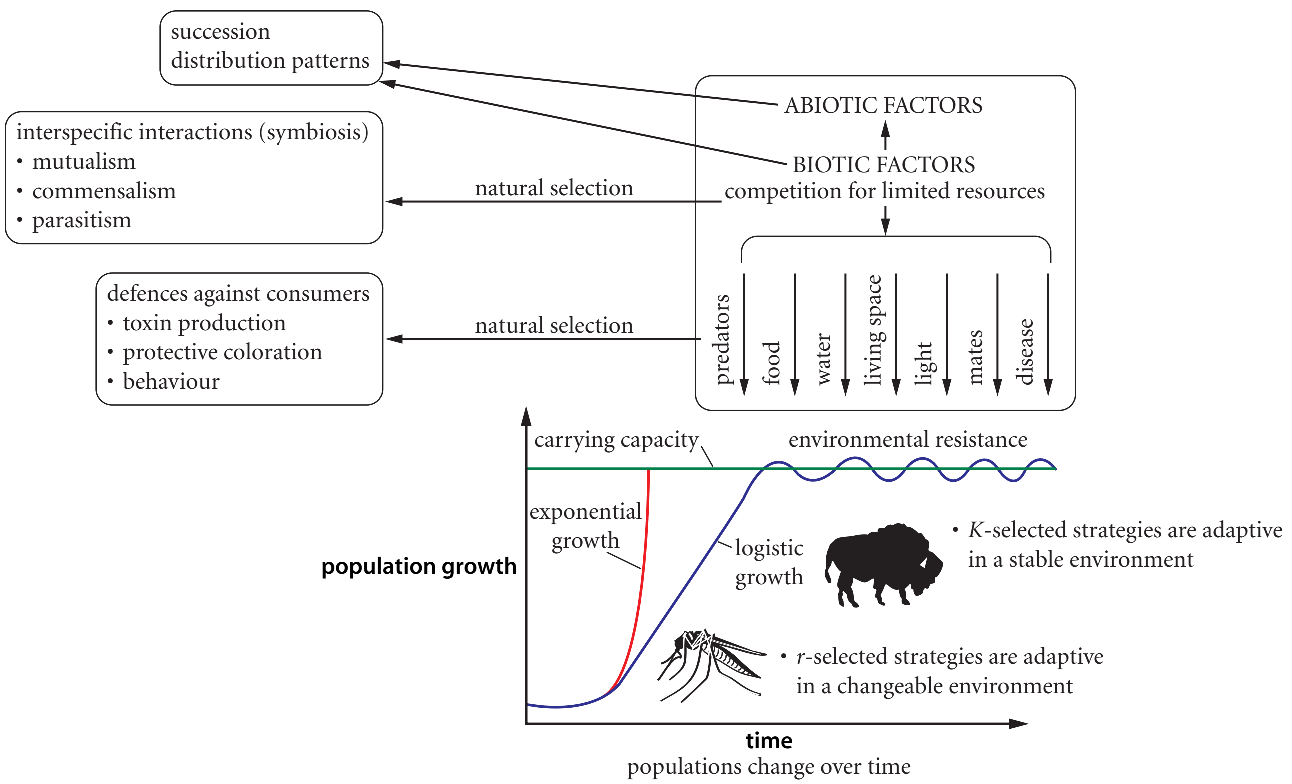
Boom or bust cycles of population growth in a changeable environment are characteristic of populations with *r*-selected strategies. In contrast, *K*-selected populations live close to the carrying capacity of their habitats.

Density-dependent and density-independent factors as well as intraspecific and interspecific competition affect a given population. Producer-consumer interactions can affect the growth of the consumer or the producer population, or both. Co-evolution may result in symbiosis. Symbiotic relationships include mutualism, commensalism, and parasitism.

Natural causes and human activities result in changes in populations and, thus, in ecological communities. Communities change over time as a result of ecological succession.

Sustainability involves meeting our social, economic, and environmental needs so that future generations can meet their needs without harming the biosphere.

Chapter 20 Graphic Organizer



Chapter 20 REVIEW

Understanding Concepts

1. Species of grasshopper that belong to the subfamily Melanoplinae are found in vast numbers across North America. About 40 species can be found in the Canadian Prairies. List three factors that might limit the exponential growth rate of populations of these species.

2. Describe a real-life example of a situation in which interspecific competition limits the population size and growth of a species.

3. Identify the four main determinants of population size.

4. Six different one-drop samples in a *Paramecium* sp. population had the following numbers of organisms: 4, 6, 5, 3, 6, and 6. If 20 drops represent 1 mL of solution, and the volume of the solution is 40 mL, calculate the size of the population.

5. For the biotic potential (r) of a population to be greater than zero, what has to be true about the birth rate and death rate of the population? Assume that there is no immigration or emigration.

6. *Helicobacter pylori* is a bacterium that lives in the human stomach. Research has shown that this bacterium can cause stomach ulcers. Research has also shown that the presence of this bacterium in the stomach can prevent the development of esophageal cancer and acid reflux in some individuals. Identify the two types of symbiotic relationships that are described here. Explain your reasoning.

7. A population of rattlesnakes contains 1000 individuals. During the year, there are 106 births, 53 deaths, 42 immigrations, and 15 emigrations. Calculate the per capita growth rate for the year.

8. The first species to invade an area and start the process of succession are usually r-selected. List the reproductive strategies of r-selected species that make them ideal candidates for this role. Explain your reasoning.

9. Identify the three theoretical distribution patterns for populations. What two factors influence the patterns of distribution?

10. In general terms, how does interspecific competition affect the growth of populations?

11. How might predation or parasitism explain why population density does not increase indefinitely?

12. In what way is the relationship between a population of herbivores and the plants they eat similar to the relationship between a predator population and a prey population?

Applying Concepts

13. **a)** Describe the shape of the age pyramid for a country with fewer young people than seniors.
b) Predict what will happen to the size of the population over time. Justify your prediction.

14. Describe the relationships among biotic potential, environmental resistance, and carrying capacity in a short paragraph.

15. Calculate the size of a population of annual plants five years in the future if the population starts with 100 plants and the growth rate is 10 plants per year. Assume that no immigration or emigration is occurring.

16. Suppose that you have just been hired to teach Grade 6 at a local school. Design an activity you could use to teach your students about factors that affect population growth in different environments.

17. Although all populations eventually face environmental resistance to continued growth, the contribution of abiotic and biotic factors to this resistance may vary from species to species. Compare a bacterium (such as *E. coli*), a plant (such as a type of tree), and a mammal (such as the snowshoe hare or the black bear) with respect to the type of factors that typically limit the growth of their populations.

18. In South Africa, some plants have co-evolved with ants that disperse their seeds. The seeds are produced with a little food package attached. The ants bring the seeds back to their nest, eat the food package and leave the seeds in the nest or discard them with their waste in a manner that protects the seeds from fire and seed-eating organisms. An invasion of another species of ants from Argentina is competing with these ants. They eat the food packages from the larger seeds only and drop the seeds on the ground, where they are exposed to fire and seed-eating organisms.
a) Identify the symbiotic relationship between the plant and the South African ants. Explain.
b) Identify the type of relationship that exists between
- the Argentine ant and the plant
- the Argentine ant and the South African ant, with respect to large seeds
- the Argentine ant and the South African ant, with respect to small seeds

c) If this situation continues, predict how the plant population might evolve. Justify your prediction, with reference to changes in allele frequencies.

19. *Caulerpa taxifolia* is an invasive species of alga that is spreading rapidly along the floor of the Mediterranean Sea. Efforts to reduce or control this species are being researched. The area supports a species of mollusk in low numbers, which feeds slowly on the alga. The plan is to boost the population of this mollusk with the hope that it will reduce the alga population. Scientists believe that there will be less risk in controlling the alga with a natural population of mollusk, rather than bringing in an introduced population. What is the main danger in boosting the numbers of a native species in order to control the alga? Explain your answer.

20. An environment in the early stages of primary succession differs significantly from the same environment in the later stages. In your notebook, prepare a table like the one below. Use the words "low" and "high" to compare the difference expected in both environments.

Comparison of Early and Late Stages of Succession

Characteristic	Early succession	Late succession
amount of available light		
biodiversity		
plant biomass		
interspecific competition		
intraspecific competition		

Making Connections

21. Although China contains only about 7 percent of Earth's arable land, its population was approximately 1.25 billion in 2001—roughly 20 percent of the total human population. Early in the 1970s, the Chinese government realized that the growth rate of China's population was unsustainable and took measures to reduce it. The Chinese government instituted a policy that limited the vast majority of families to only one child and strictly enforced the policy. Describe the benefits and drawbacks of the one-child policy.

22. Forest tent caterpillars (*Malacosoma disstria*) are common throughout North America. In Alberta, they are found mainly in the boreal forest, aspen parkland, and Rocky Mountains. While they feed on a variety of host plants, they most commonly consume leaves of the trembling aspen. A study of the forest tent caterpillar population was conducted in an Alberta forest. Two areas, a fragmented forest and a continuous forest, were sampled at five different sites. The data obtained is presented in the table below.

Caterpillar Population Density in Two Areas of a Forest

Site	Population density in fragmented forest (caterpillars per leaf)	Population density in continuous forest (caterpillars per leaf)
A	5	8
B	12	6
C	8	10
D	4	9
E	11	3

a) Calculate the average density (caterpillars per leaf) of the caterpillar population in both areas.

b) If a tree has about 2000 leaves, determine the size of the caterpillar population on a tree in both forest samples.

c) What assumption did you make regarding the distribution of caterpillars in a tree to calculate the answer to part (b)?

d) Some of the caterpillars that were collected were brought back to the laboratory. Upon analysis, scientists discovered that flies of the families Tachinidae and Sarchophagidae had infected the caterpillars. Identify the population interaction taking place between the flies and the caterpillars.

e) The table below indicates the number of infected caterpillars in samples from each area. Calculate the average infection rate of the caterpillars for each area.

Numbers of Infected Caterpillars in Two Areas of a Forest

Sample size	Number infected in fragmented forest samples	Sample size	Number infected in continuous forest samples
10	3	6	2
12	2	8	3
8	2	8	4
12	4	12	6

f) Based on your answer to part (b), what reasonable conclusion can you make about the effect of the flies on the caterpillar populations in both areas?

g) Is this the only possible explanation for the size differences between the caterpillar populations in the two areas? Justify your answer.

h) Forest tent caterpillars have been present in forested areas for a long time. A heavy infestation tends to occur every 6 to 16 years, and severe infestations can last from 2 to 4 years. These infestations can cause an ecological disturbance in a forested area. What type of succession would take place after a disturbance caused by an infestation of forest tent caterpillars?

Career Focus: Ask a Science Journalist

Science journalist Cheryl Croucher has a passion for helping Albertans understand scientific and environmental issues that require public decisions. In the 1990s, she was CBC Radio's first-ever environment commentator. In 2001, she started her Innovation Alberta Omnimedia Web site, where she has made available hundreds of science-related radio programs, broadcast on CKUA, as both audio files and transcripts. Based in Edmonton, she interviews scientists across Alberta.

Q What do you, as a science communicator, see as the biggest obstacle to the public's understanding of science?

People think, "Let's see what the scientists say, because they'll help us make the decisions." Because we don't really understand the scientific method, we get confused when they don't have a black-and-white answer. They're asking more *questions*! One of my objectives is to help people become informed decision-makers so that when we do face issues, we have a better understanding of the bigger picture, and then scientists can help us make decisions.

Q How did you become a science journalist?

I was never a science student or keenly interested in science. However, when I started doing my consumer commentaries on CBC, by about 1987, probably half were dealing with environmental issues. Then I met people through the stories I was doing who were taking the scientific and technological approach to finding solutions.

Q Why did you found Innovation Alberta? What audience are you trying to reach?

I want to help people become informed decision-makers. Let's not make scientists gods; let's understand where they fit into the scheme of things.

Q You sometimes present your audience with tough issues. For example, one of your programs addressed the diminishing woodland caribou population. You reported that some herds had decreased by forty percent. It seems that in the new forests that grow following deforestation, caribou populations are reduced, while deer populations explode. Scientists have recommended killing deer, whose populations have exploded, to restore a diverse balance.

People will say, "Oh, you can't kill those deer, they're so *cute*!" But if you can take people through the process, it's easier for them to come to terms with what has to be done. It's a balancing act. You're dealing with trade-offs.

Q An additional tough issue is that scientists think that conservation efforts should focus on healthy caribou herds. But concerned listeners might be more motivated to help the most distressed herds. Won't many listeners find this a hard choice?

If you can take people through the process, it's easier for them to come to terms with what has to be done and the implications. A lot of it is getting rid of the myths and making an *informed* decision.

Q In the past, there has been a lot of contention between the forestry industry and Aboriginal peoples. Have you seen any growth in mutual respect over the years?

There has actually been tremendous progress. First of all, there is now recognition that traditional knowledge is legitimate; it's something we can also incorporate into Western science. The Aboriginal people are becoming very vocal and involved, saying "You have to pay attention; we *do* have something to contribute. If you're a hunter and gatherer, you need to *know about* the animals you are hunting." I have watched the change over time from "We're better than you" (on both sides) to an understanding that we each have something to contribute.

Q Overall, have you seen any change over time in public attitudes on environmental issues?

I think people are much more aware now. A lot of programs have become just part of our daily life, like recycling and water conservation. These things change public attitudes bit by bit.

Q If a young person wanted to go into science journalism, what advice would you give?

The key to being a good science journalist is really being a good journalist. As a journalist, you ask questions, you observe, you gather information, and you help put it into perspective for people.

Other Careers Related to Science Communications

Radio/TV Broadcaster Journalists who work in electronic media develop personal presentation skills, as well as research and writing skills. In addition to higher education, they learn on the job by volunteering at university radio stations and cable television programs. Journalism schools look for applicants, for both print and broadcast media training, who have already shown an interest in journalism. There is a growing demand for broadcasters who can present science issues effectively.

Web Site Designer/Developer Graphic artists build web sites that inform and entertain, using a variety of techniques. Courses in graphic arts and web design are offered at universities and community colleges across Canada. Students often begin by developing a portfolio of artwork or web sites in high school. The portfolio enables a university or college to assess the student's potential. Many cutting-edge web sites focus on presenting science to the public.

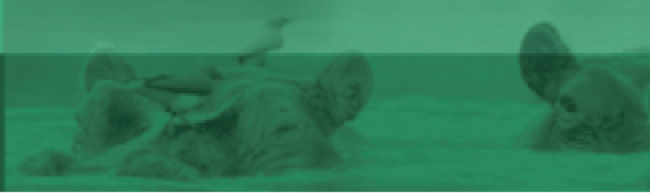
Science Teacher Science teachers usually begin their careers by choosing mathematics and science subjects in high school, and majoring in a science subject at a university. Then they take teacher training courses, which include theoretical and practical components. Helping students understand science issues can be a very rewarding career.

Wildlife Biologist Wildlife biologists play a critical role in conservation policy by determining the facts about changes in native animal populations, and by linking these facts to either natural cycles or newly introduced causes. Usually, a wildlife biologist focusses on sciences in high school and continues to study sciences at university, with a focus on animal biology.

Forest Science Biologist The management of valuable forest resources requires a forest science biologist to have an extensive knowledge of trees and their habitats. Usually, a forest science biologist focusses on sciences in high school, and then continues to study sciences at university, with a focus on plant biology.

Go Further…

1. Are decisions about animal population management based strictly on numbers? What other factors might play a role in public decision making?
2. How might traditional Aboriginal knowledge of Alberta's forest ecology help scientists understand it better?
3. Why does the public need to understand the scientific method in order to make informed decisions about environmental policy?



UNIT 8 REVIEW

Understanding Concepts

1. In a population of grey and white pigeons (*Columba* sp.), the phenotype frequency for white feather colour is the same as the genotype frequency for the *bb* genotype. This is because white feather colour is a recessive trait. The genotype frequencies for the population are 81.0 percent *BB*, 18.0 percent *Bb*, and 1.00 percent *bb*. Determine the phenotype frequency (as a percentage) for grey feathers.

2. If 16 percent of individuals in a population have attached ear lobes, a recessive trait in humans, calculate the frequency of the dominant allele. Assume the population is at genetic equilibrium.

3. Is a population that is at genetic equilibrium evolving? Given reasons to support your answer.

4. Define intraspecific competition. Explain how insects reduce intraspecific competition between adults and offspring.

5. Distinguish between the variables q and q^2 in the Hardy-Weinberg equation.

6. Explain why the effects of genetic drift are more significant in small populations than in large ones.

7. Ethion is an insecticide that kills leaf-eating insects such as mites. A species of mite develops a mutation over time that allows it to survive in the presence of ethion. Is this mutation an example of microevolution? Explain your answer.

8. Describe the relationship between mutation and natural selection.

9. The elaborate tail of the peacock (*Pavo cristatus*) is approximately 120 cm to 150 cm long, while the tail of the peahen is quite short. The long tail reduces the male bird's ability to maneuver and fly and makes him more conspicuous to predators. Suggest at least one reason why this cumbersome structure has not been eliminated by natural selection.

10. The yield of a field of wheat or canola increases when herbicides are used to control the growth of weeds.

a) Identify the population interaction between the crop and the weeds.

b) Explain why the yield increases when the weed population is controlled.

11. In studying a population of lizards, scientists sampled 47 sections of a habitat. Each section was 29 km^2. It was found that the density of the lizards was $\frac{1}{3.8\ km^2}$.

a) Calculate the size of the lizard population living in the area.

b) What assumption did you make regarding the distribution of this population throughout its habitat when calculating your results?

12. Identify the distribution pattern illustrated in the following examples:

a) an apple orchard

b) plants that reproduce asexually by sending out runners from the parent

c) territorial birds of prey

d) an adult mosquito population

e) *Homo sapiens*

13. Identify the population interaction in each of the following examples.

a) The Nile crocodile (*Crocodylus niloticus*) opens its mouth, and the crocodile bird (*Pluvianus aegyptius*) eats the leeches that are attached to its gums and tongue.

b) Spanish moss (*Tillandsia usneoides*) is an epiphyte, a plant that lacks roots and attaches to the branches of trees for support. The epiphyte obtains all its needs for photosynthesis from the air. The supporting plant is unharmed.

c) Tiny hookworm larvae penetrate the skin between the toes of a human and migrate to the lungs where they mature. The adults then are coughed up and enter the digestive tract where they drill tiny holes in the intestine and digest human blood for nutrition.

d) Some insects have shapes that resemble bird droppings. Some have swellings on their legs that look like seeds stuck in the bird droppings.

e) African sleeping sickness is caused by a unicellular organism, *Trypansoma* sp., which obtains nutrients from its host's blood. It is transferred to humans when they are bitten by an infected Tsetse fly (*Glossina* sp.).

f) The Torsalo fly (*Dermatobia hominis*) catches insects such as mosquitoes and glues their eggs to the underside of their bodies. When the mosquitoes bite a human or other mammal, the heat from the skin causes rapid development of the eggs into larvae. The larvae penetrate the skin where they form a cyst or boil and feast on the mammal's blood as they mature.

14. The monarch butterfly is tolerant to the bitter chemicals found in the milkweed plant. Monarch caterpillars feed on the milkweed leaves, storing bitter chemicals from the host plant, which causes them to taste terrible and provides monarch butterflies with protection from predators, such as birds. The viceroy butterfly has the same coloration as the monarch butterfly. What kind of mimicry would the viceroy butterfly be exhibiting if it were
   a) poisonous?
   b) not poisonous?

15. Some species of sponges secrete chemicals that inhibit the growth of other sponges in the immediate area. What type of distribution would you expect to find in areas where this process is occurring? Explain.

16. How can you account for the fact that, in North America, populations of large animals such as bears, moose, and deer are more affected by a loss of habitat than smaller animals such as gophers and squirrels?

17. Give an example of succession and describe two biotic and abiotic factors that change during this process.

18. Describe the age pyramid representing a stable population where there is roughly the same proportion of people in each stage of development.

Applying Concepts

19. If a population has two alleles for a particular locus, *B* and *b*, and if the allele frequency of *B* is 0.70, what percentage of the next generation is expected to be heterozygous for this trait, if the population is at genetic equilibrium?

20. If 1 in 10 000 babies is born with albinism, a recessive trait in humans, calculate the frequency of:
   a) the recessive allele
   b) the dominant allele
   c) the heterozygotes in the population

21. The presence of freckles is a dominant trait in humans. Scientists were studying a population in which half of the individuals had the recessive trait. Calculate the frequency of the freckle allele (*F*) that would lead to these results.

22. A student sampled 100 domestic cats (*Felis catus*) from a population of which 84 had black fur and 16 had white fur. In this species, black fur colour is dominant to white fur.
   a) Determine the frequency of each allele in the population.
   b) What percentage of the population is expected to be heterozygous for this trait?

23. Tay-Sachs disease causes severe developmental and mental disabilities that occur four to eight months after birth. The disease is due to inheritance of a recessive allele and is especially prevalent in the Ashkenazi (European) Jewish community, affecting 1 out of every 2500 babies.
   a) Determine the frequency of this allele in the Ashkenazi Jewish population.
   b) What proportion of the Ashkenazi Jewish population is expected to be a carrier for this trait?

24. In a class of 36 students tested for the ability to roll their tongues, 12 were found to be non-rollers, a recessive trait.
   a) Determine the frequency of each allele in this population.
   b) How many of the 24 tongue rollers would you expect to be heterozygous?

25. In grey squirrels, dark coat colour is dominant to light coat colour. The study of a population of squirrels in a city over a five-year period produced the following results:

Year	Number of dark-coloured squirrels	Number of light-coloured squirrels
1	152	24
2	132	20
3	177	27
4	98	14
5	49	7

   a) Calculate the frequency of each allele and genotype in the population for year 1 and year 5 of the study.
   b) Is this population evolving? Explain.
   c) Identify three environmental conditions that could favour the selection of one genotype or phenotype in the squirrel population.
   d) Would the data for this study have been any different if light-coloured fur was dominant to black? Explain.

26. The following table provides estimations of the global population from 1970 to 2000.

Estimated Global Population 1970–2000

Year	Estimated global population (in millions)
1970	3699
1980	4440
1990	5280
2000	6068

a) Calculate the per capita growth rate for each of the decades.
b) Describe the trend in the per capita growth rate of the human population during this time period.
c) In 2005, the per capita growth rate for the human population was 0.012. Why might the population still increase substantially even though the per capita growth rate has decreased?
d) Identify three limiting factors that you think might slow down the growth of the human population.

27. The Loggerhead Shrike (*Lanius ludovicianus*) is considered by the Committee on the Status of Endangered Wildlife in Canada to be of "special concern" in Alberta. Within a study area in 1998, 232 shrikes were observed at 144 locations. Over the next five years, 52 new shrikes were born and 116 died or left the area.
a) Calculate the growth rate of this shrike population during the study period.
b) How large was the shrike population in 2003?

28. A field has an area of 1 ha (100 m × 100 m). If sunflower plants (*Helianthus annuus*) produce the highest number of seeds at a density of 9 plants/m^2, calculate the maximum number of plants that can grow in this field to allow production of the most seeds. Identify four limiting factors that could cause decreased production in the plants, should the density increase.

29. A population of 812 gophers is growing exponentially in a field. The population has a per capita growth rate of 0.30.
a) What will the size of this population be after one year?
b) After two years?
c) Identify four factors that would limit the growth rate of this population as it reaches the carrying capacity of the environment.
d) Classify these factors as density-dependent or density-independent.

30. A study of a population of snails in a 5 m^2 area produced the following results over a seven-year period.

Comparison of Snail Density over a Seven-year Period

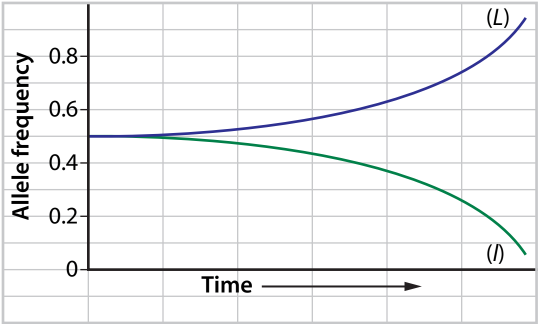
Year of Study	Density (snails/m^2)
1	17.5
2	70.2
3	108.9
4	115.7
5	129
6	143.8
7	87.7

a) Graph the results for density versus time.
b) Calculate the per capita growth rate between year 1 and year 3 of the study.
c) Determine the size of the population in year six.
d) List and explain three factors that might have caused a decrease in the population density in the last year.

Making Connections

31. The common fruit fly, *Drosophilia melanogaster*, has a life cycle of 14 days. In this species, long wing (*L*) is dominant to vestigial or short wing (*l*). Individuals with short wings are unable to fly. In culture, they are found walking on the medium at the bottom of the container where the larvae grow. Equal numbers of homozygous long and short wing flies were placed in a large container with an adequate food supply to start a population. Flies were counted every two weeks for a period of three months, and the frequency of each allele in the population was determined. The following data were obtained.

Change in frequency over time of the long wing (*L*) and short wing (*l*) alleles in *Drosophila melanogaster*

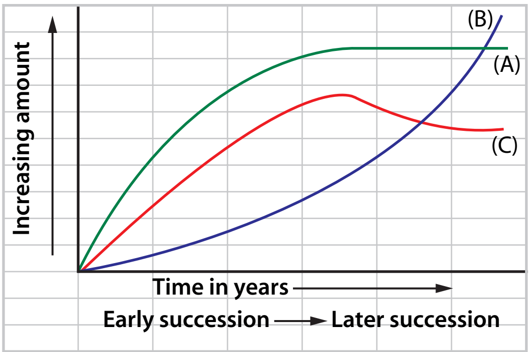


a) Describe what is happening to the frequency of each allele in the population during this time.
b) Use your understanding of the Hardy-Weinberg model to explain the data.

c) If this experiment were to continue for a full year, do you think the frequency of the short wing allele (l) will ever become 0? Explain your reasoning.

32. The graph below shows the relationship between net productivity (A), biomass (B), and species diversity (C) as succession in an area takes place over time. The net productivity is the amount of energy available to the next tropic level.

Relationship between net productivity (A), biomass (B), and diversity (C) during stages of succession



a) Describe how each factor changes as succession occurs.

b) Explain these results.

33. Populations of many of the species that are considered to be at risk (threatened or endangered) are *K*-selected compared to other populations. Give two reasons why such species might be more at risk, explaining your reasoning.

34. As habitats around the world are lost, many species become extinct before we have even discovered them. What advantages are provided by high levels of species diversity, genetic diversity, and ecosystem diversity? In other words, what is the value of biodiversity? How might ecologists or the citizens of countries with high levels of biodiversity that are rapidly being lost use this "value" to preserve habitats and species? Answer this question in the form of a short essay, perhaps focussing on one province, country, or region of the world.

35. Examine the age pyramids shown below.

a) Predict which population will grow the fastest over time. Justify your response.

b) How much would a decrease in the birth rate affect the growth rate of each of the populations? Explain your answer.

c) Suggest how the age structure of each population could affect the economic well-being of each country.

d) Explain how the spread of HIV could affect the growth rate of Nigeria's population (compared to your prediction in part (a)).