5 Populations

Big idea: Interdependence in Nature

Q: What factors contribute to changes in populations?

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INSIDE:

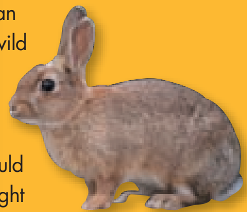
- 5.1 How Populations Grow
- 5.2 Limits to Growth
- 5.3 Human Population Growth

Millions of red crabs live on Christmas Island in the Indian Ocean. Each year the entire adult crab population migrates from forest to sea to breed, making daily life a bit tricky for human residents!

- Untamed Science Video
- Chapter Mystery

CHAPTER
MYSTERY

A PLAGUE OF RABBITS



In 1859, an Australian farmer released 24 wild European rabbits from England on his ranch. "A few rabbits" he said, "could do little harm and might provide a touch of home, in addition to a spot of hunting."

Seven years later, he and his friends shot 14,253 rabbits. In ten years, more than 2 million rabbits were hunted on that farm alone! But hunters' glee turned into nationwide despair. That "touch of home" was soon covering the countryside like a great gray blanket. The millions of rabbits devoured native plants and pushed native animals to near extinction. They made life miserable for sheep and cattle ranchers.

These cute, fuzzy creatures weren't a problem in England. Why did they turn into a plague in Australia? Could they be stopped? How? As you read this chapter, look for clues on factors that affect population growth. Then, solve the mystery.

Never Stop Exploring Your World. Finding the solution to the rabbit population mystery is only the beginning. Take a video field trip with the ecogeeks of Untamed Science to see where this mystery leads.

UntamedScience™

5.1 How Populations Grow

Key Questions

🔑 *How do ecologists study populations?*

🔑 *What factors affect population growth?*

🔑 *What happens during exponential growth?*

🔑 *What is logistic growth?*

Vocabulary

population density • age structure • immigration • emigration • exponential growth • logistic growth • carrying capacity

Taking Notes

Concept Map As you read, use the highlighted vocabulary words to create a concept map that organizes the information in this lesson.

THINK ABOUT IT In the 1950s, a fish farmer in Florida tossed a few plants called hydrilla into a canal. Hydrilla was imported from Asia for use in home aquariums because it is hardy and adaptable. The fish farmer assumed that hydrilla was harmless. But the few plants he tossed away reproduced quickly . . . and kept on reproducing. Today, their offspring strangle waterways across Florida and many other states. Tangled stems snag boats in rivers and overtake habitats; native water plants and animals are disappearing. Why did these plants get so out of control? Is there any way to get rid of them?

Meanwhile, people in New England who fish for a living face a different problem. Despite hard work and new equipment, their catch has dropped dramatically. The cod catch in one recent year was 3048 metric tons. Back in 1982, it was 57,200 metric tons—almost 19 times higher! Where did all the fish go? Can anything be done to increase their numbers?

Describing Populations

🔑 ***How do ecologists study populations?***

At first glance, the stories of hydrilla and cod may seem unrelated. One is about plants growing out of control, and the other is about fish disappearing. Yet both involve dramatic changes in the size of a population. Recall that a population is a group of organisms of a single species that lives in a given area. 🔑 **Researchers study populations' geographic range, density and distribution, growth rate, and age structure.**

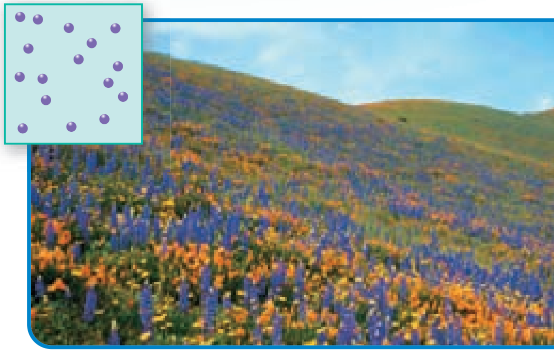
FIGURE 5–1 Invasive Hydrilla Hydrilla has spread through most of Florida in just a few decades. Efforts to control the waterweed cost millions of dollars a year.

Geographic Range The area inhabited by a population is called its geographic range. A population's range can vary enormously in size, depending on the species. A bacterial population in a rotting pumpkin, for example, may have a range smaller than a cubic meter. The population of cod in the western Atlantic, on the other hand, covers a range that stretches from Greenland down to North Carolina. The natural range of one hydrilla population includes parts of southern India and Sri Lanka. The native range of another hydrilla population was in Korea. But humans have carried hydrilla to so many places that its range now includes every continent except Antarctica, and it is found in many places in the United States.

Density and Distribution **Population density** refers to the number of individuals per unit area. Populations of different species often have very different densities, even in the same environment. For example, a population of ducks in a pond may have a low density, while fish in the same pond community may have a higher density. *Distribution* refers to how individuals in a population are spaced out across the range of the population—randomly, uniformly, or mostly concentrated in clumps, as shown in **Figure 5–2.**

Growth Rate A population's growth rate determines whether the size of the population increases, decreases, or stays the same. Hydrilla populations in their native habitats tend to stay more or less the same size over time. These populations have a growth rate of around zero. In other words, they neither increase nor decrease in size. The hydrilla population in Florida, by contrast, has a high growth rate—which means that it increases in size. Populations can also decrease in size, as cod populations have been doing. The cod population has a negative growth rate.

Age Structure To fully understand a plant or animal population, researchers need to know more than just the number of individuals it contains. They also need to know the population's **age structure**—the number of males and females of each age a population contains. Why? Because most plants and animals cannot reproduce until they reach a certain age. Also, among animals, only females can produce offspring.



A. Random

B. Uniform

C. Clumped

FIGURE 5–2 Patterns of Distribution The dots in the inset illustrations represent individual members of a population. **A.** Purple lupines grow randomly in a field of wildflowers. **B.** King penguin populations show uniform spacing between individuals. **C.** Striped catfish form tight clumps.

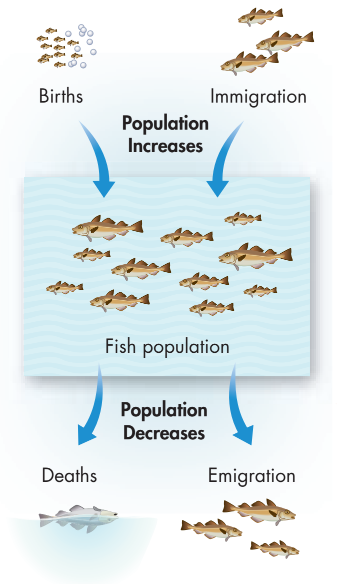


FIGURE 5–3 Natural Factors That Affect the Growth of a Fish Population The numbers of fish that hatch, die, enter, or leave the population affect the growth of the population. **Use Models** ***How would you expand this model to include the effects of fishing?***

Population Growth

What factors affect population growth?

What determines whether a population grows, shrinks, or stays the same size? A population will increase or decrease in size depending on how many individuals are added to it or removed from it, as shown in **Figure 5–3.** **The factors that can affect population size are the birthrate, death rate, and the rate at which individuals enter or leave the population.**

Birthrate and Death Rate Populations can grow if more individuals are born than die in any period of time. In other words, a population can grow when its birthrate is higher than its death rate. If the birthrate equals the death rate, the population may stay the same size. If the death rate is greater than the birthrate, the population is likely to shrink. Note that *birth* means different things in different species. Lions are born much like humans are born. Codfish, however, release eggs that hatch into new individuals.

Immigration and Emigration A population may grow if individuals move into its range from elsewhere, a process called **immigration** (im uh GRAY shun). Suppose, for example, that an oak grove in a forest produces a bumper crop of acorns one year. The squirrel population in that grove may increase as squirrels immigrate in search of food. On the other hand, a population may decrease in size if individuals move out of the population's range, a process called **emigration** (em uh GRAY shun). For example, a local food shortage or overcrowding can cause emigration. Young animals approaching maturity may emigrate from the area where they were born to find mates or establish new territories.

Exponential Growth

What happens during exponential growth?

If you provide a population with all the food and space it needs, protect it from predators and disease, and remove its waste products, the population will grow. Why? The population will increase because members of the population will be able to produce offspring. After a time, those offspring will produce their own offspring. Then, the offspring of *those* offspring will produce offspring. So, over time, the population will grow.

But notice that something interesting will happen: The size of each generation of offspring will be larger than the generation before it. This situation is called exponential (eks poh NEN shul) growth. In **exponential growth,** the larger a population gets, the faster it grows. **Under ideal conditions with unlimited resources, a population will grow exponentially.** Let's examine why this happens under different situations.

MYSTERY CLUE

What kind of growth does the rabbit population in Australia exhibit? Why does that present a problem?

Organisms That Reproduce Rapidly We begin a hypothetical experiment with a single bacterium that divides to produce two cells every 20 minutes. We supply it with ideal conditions—and watch. After 20 minutes, the bacterium divides to produce two bacteria. After another 20 minutes, those two bacteria divide to produce four cells. At the end of the first hour, those four bacteria divide to produce eight cells.

Do you see what is happening here? After three 20-minute periods, we have $2 \times 2 \times 2$, or 8 cells. Another way to say this is to use an exponent: 2^3 cells. In another hour (six 20-minute periods), there will be 2^6, or 64 bacteria. In just one more hour, there will be 2^9, or 512. In one day, this bacterial population will grow to an astounding 4,720,000,000,000,000,000,000 individuals. What would happen if this growth continued without slowing down? In a few days, this bacterial population would cover the planet!

If you plot the size of this population on a graph over time, you get a J-shaped curve that rises slowly at first, and then rises faster and faster, as shown in **Figure 5–4.** If nothing interfered with this kind of growth, the population would become larger and larger, faster and faster, until it approached an infinitely large size.

Organisms That Reproduce Slowly Of course, many organisms grow and reproduce much more slowly than bacteria. For example, a female elephant can produce a single offspring only every 2 to 4 years. Newborn elephants take about 10 years to mature. But as you can see in **Figure 5–4,** if exponential growth continued, the result would be impossible. In the unlikely event that all descendants of a single elephant pair survived and reproduced, after 750 years there would be nearly 20 million elephants!

Organisms in New Environments Sometimes, when an organism is moved to a new environment, its population grows exponentially for a time. That's happening with hydrilla in the United States. It also happened when a few European gypsy moths were accidentally released from a laboratory near Boston. Within a few years, these plant-eating pests had spread across the northeastern United States. In peak years, they devoured the leaves of thousands of acres of forest. In some places, they formed a living blanket that covered the ground, sidewalks, and cars.

In Your Notebook *Draw a growth curve for a population of waterweed growing exponentially.*

BUILD Vocabulary

RELATED WORD FORMS An exponent indicates the number of times a number is multiplied by itself. The adjective *exponential* describes something that is expressed using exponents—such as the rate of growth.

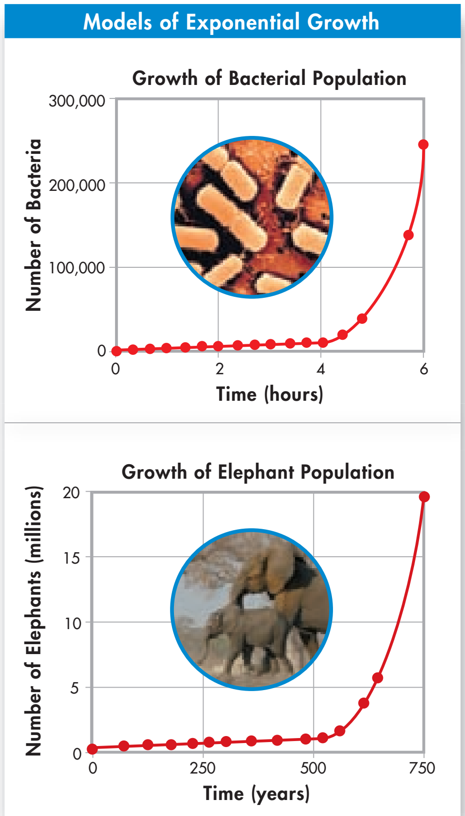


FIGURE 5–4 Exponential Growth In the presence of unlimited resources and in the absence of predation and disease, populations will grow exponentially. Bacteria, which reproduce rapidly, can produce huge populations in a matter of days. It would take elephants, which reproduce slowly, a few hundred years. Both hypothetical graphs show the characteristic J-shape of exponential growth.

Logistic Growth

What is logistic growth?

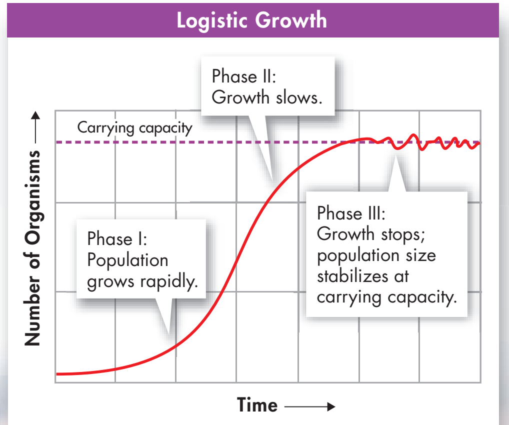
This ability of populations to grow exponentially presents a puzzle. Obviously, bacteria, elephants, hydrilla, and gypsy moths don't cover the Earth. This means that natural populations don't grow exponentially for long. Sooner or later, something—or several "somethings"—stops exponential growth. What happens?

Phases of Growth One way to begin answering this question is to watch how populations behave in nature. Suppose that a few individuals are introduced into a real-world environment. **Figure 5–5** traces the phases of growth that the population goes through.

VISUAL SUMMARY

LOGISTIC GROWTH

FIGURE 5–5 Real-world populations, such as those of the rhinoceros, show the characteristic S-shaped curve of logistic growth. As resources become limited, population growth slows or stops, leveling off at the carrying capacity.



- ***Phase 1: Exponential Growth*** After a short time, the population begins to grow exponentially. During this phase, resources are unlimited, so individuals grow and reproduce rapidly. Few individuals die, and many offspring are produced, so both the population size and the rate of growth increase more and more rapidly.
- ***Phase 2: Growth Slows Down.*** In real-world populations, exponential growth does not continue for long. At some point, the rate of population growth begins to slow down. This does not mean that the population size decreases. The population still grows, but the rate of growth slows down, so the population size increases more slowly.
- ***Phase 3: Growth Stops.*** At some point, the rate of population growth drops to zero. This means that the size of the population levels off. Under some conditions, the population will remain at or near this size indefinitely.

The Logistic Growth Curve The curve in **Figure 5–5** has an S-shape that represents what is called **logistic growth.** **Logistic growth occurs when a population's growth slows and then stops, following a period of exponential growth.** Many familiar plant and animal populations follow a logistic growth curve.

What kinds of changes in a population's characteristics can produce logistic growth? Remember that a population grows when more organisms are born (or added to it) than die (or leave it). Thus, population growth may slow for several reasons. Growth may slow because the population's birthrate decreases. Growth may also slow if the death rate increases—or if births fall and deaths rise together. Similarly, population growth may slow if the rate of immigration decreases, the rate of emigration increases, or both. There are several reasons why these rates might change in a population, as you will see in the next lesson.

Carrying Capacity When the birthrate and the death rate are the same, and when immigration equals emigration, population growth stops. The population may still rise and fall somewhat, but the ups and downs average out around a certain population size. If you look again at **Figure 5–5,** you will see a broken, horizontal line through the region of the graph where population growth levels off. The point at which that line intersects the *y*-axis represents what ecologists call the carrying capacity. **Carrying capacity** is the maximum number of individuals of a particular species that a particular environment can support. Once a population reaches the carrying capacity of its environment, a variety of factors act to stabilize it at that size.

Analyzing Data

Multiplying Rabbits

Suppose that a pair of rabbits produces six offspring: three males and three females. Assume that no offspring die.

1. **Calculate** If each pair of rabbits breeds only once, how many offspring would be produced each year for five generations? MATH
2. **Interpret Graphs** Construct a graph of your data. Plot time on the *x*-axis and population on the *y*-axis. What type of growth is the rabbit population going through after 5 years?

5.1 Assessment

Review Key Concepts

1. a. **Review** List four characteristics that are used to describe a population.
   b. **Infer** On your travels through eastern Canada and the United States, you notice gray squirrels everywhere. What can you infer about the squirrels' geographic range?
2. a. **Review** What natural factors can change a population's size?
   b. **Relate Cause and Effect** More dandelion seedlings develop in a lawn than dandelion plants are removed. What is likely to happen to the lawn's dandelion population?
3. a. **Review** When do populations grow exponentially?
   b. **Apply Concepts** Why does exponential growth show a characteristic J-shaped curve?
4. a. **Review** What is the characteristic shape of a logistic growth curve?
   b. **Explain** Describe when logistic growth occurs.
   c. **Form a Hypothesis** What factors might cause the carrying capacity of a population to change?

PRACTICE PROBLEM

5. Suppose you are studying a population of sunflowers growing in a small field. How would you determine the population density of sunflowers in a square meter of the field and in the entire field? Describe your procedure.

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Biology & Society

What Can Be Done About Invasive Mussels?

It's hard to imagine that shellfish could cause millions of dollars worth of trouble every year. Meet the zebra mussel and the quagga mussel. Both species were carried to the Great Lakes in the mid-1980s from Eastern Europe in ships' ballast waters (water carried inside boats for balance). As adults, these mussels attach to almost any hard surface, including water pipes and boat hulls. After just a few years, both species colonized the entire Great Lakes region. Since then, they have been spread by recreational boaters who unknowingly carry mussels attached to their boats. By 2008, zebra mussels had been reported in 24 states; quagga mussels are already known in 14 states.

Why have these mussels become such pests? In American waterways, they escape whatever environmental factors keep their numbers in check in their native European habitats. As a result, these introduced species have become invasive species whose exponential growth produces huge populations at high densities—over 10,000 mussels per square meter of water in some places! These mussels grow in layers up to 20 centimeters thick, clogging water pipes that supply power plants and water treatment facilities. They also upset aquatic food webs, filtering so much plankton from the water that some native fishes and shellfish starve. What can be done to control such invasive species?

Zebra mussels clog water intake pipes.

The Viewpoints

Invasive Species Should Be Destroyed A number of groups contend that zebra mussels should be removed completely. Some engineers are developing robotic submarines that can remove mussels from pipes. Some chemists are testing chemicals for the potential to destroy or disrupt the life cycle of zebra mussels. Other scientists are adding chemicals to paints and plastics to prevent mussels from attaching to new surfaces.

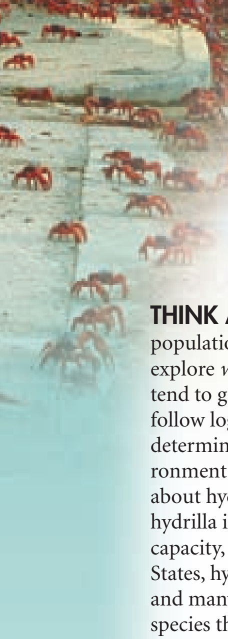
Invasive Species Management Should Focus on Control and Prevention Others argue that efforts to physically remove or chemically poison invasive mussels offer only temporary control. The population bounces right back. These removal efforts are also incredibly expensive. In the Great Lakes alone, more than $200 million is spent each year in efforts to get rid of zebra and quagga mussels.

Therefore, many scientists believe that there is no way to remove these mussels and other established invasive species. Instead, these scientists attempt to control the growth of populations and prevent transfer of invasive species to new areas. One regulation, for example, could require boaters to filter and chemically clean all ballast water. Meanwhile, the search continues for some kind of control that naturally limits mussel numbers when they rise.

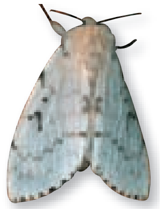
Research and Decide

1. Analyze the Viewpoints Research the current status of invasive mussel populations and the approaches being used to prevent the spread of these and other invasive aquatic species. What trends are zebra mussel populations showing?

2. Form an Opinion What kinds of natural population controls do you think would manage these invasive mussels most effectively? Why?



5.2 Limits to Growth



THINK ABOUT IT Now that you've seen *how* populations typically grow in nature, we can explore *why* they grow as they do. If populations tend to grow exponentially, why do they often follow logistic growth? In other words, what determines the carrying capacity of an environment for a particular species? Think again about hydrilla. In its native Asia, populations of hydrilla increase in size until they reach carrying capacity, and then population growth stops. But here in the United States, hydrilla grows out of control. The same is true of gypsy moths and many other introduced plant and animal species. Why does a species that is "well-behaved" in one environment grow out of control in another?

Key Questions

What factors determine carrying capacity?

What limiting factors depend on population density?

What limiting factors do not typically depend on population density?

Vocabulary

limiting factor
density-dependent limiting factor
density-independent limiting factor

Taking Notes

Outline Make an outline using the green and blue headings in this lesson. Fill in details as you read to help you organize the information.

Limiting Factors

What factors determine carrying capacity?

Recall that the productivity of an ecosystem can be controlled by a limiting nutrient. A limiting nutrient is an example of a general ecological concept: a limiting factor. In the context of populations, a **limiting factor** is a factor that controls the growth of a population.

As shown in **Figure 5–6,** there are several kinds of limiting factors. Some—such as competition, predation, parasitism, and disease—depend on population density. Others—including natural disasters and unusual weather—do not depend on population density. **Acting separately or together, limiting factors determine the carrying capacity of an environment for a species.** Limiting factors keep most natural populations somewhere between extinction and overrunning the planet.

Charles Darwin recognized the importance of limiting factors in shaping the history of life on Earth. As you will learn in Unit 5, the limiting factors we describe here produce the pressures of natural selection that stand at the heart of evolutionary theory.

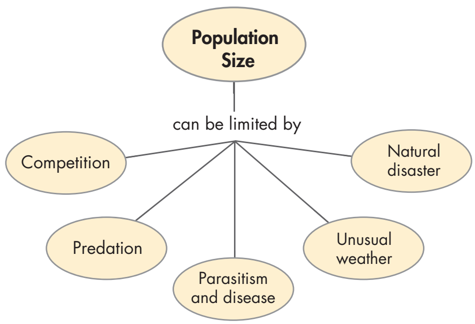


FIGURE 5–6 Limiting Factors Many different factors can limit population growth. Some of these factors depend on population density, while others do not. **Infer** ***How might each of these factors increase the death rate in a population?***

FIGURE 5–7 **Competition** Male wolves may fight one another for territory or access to mates.

Density-Dependent Limiting Factors

What limiting factors depend on population density?

Density-dependent limiting factors operate strongly only when population density—the number of organisms per unit area—reaches a certain level. These factors do not affect small, scattered populations as much. **Density-dependent limiting factors include competition, predation, herbivory, parasitism, disease, and stress from overcrowding.**

Competition When populations become crowded, individuals compete for food, water, space, sunlight, and other essentials. Some individuals obtain enough to survive and reproduce. Others may obtain just enough to live but not enough to enable them to raise offspring. Still others may starve to death or die from lack of shelter. Thus, competition can lower birthrates, increase death rates, or both.

Competition is a density-dependent limiting factor, because the more individuals living in an area, the sooner they use up the available resources. Often, space and food are related to one another. Many grazing animals compete for territories in which to breed and raise offspring. Individuals that do not succeed in establishing a territory find no mates and cannot breed.

Competition can also occur among members of different species that are attempting to use similar or overlapping resources. This type of competition is a major force behind evolutionary change.

Predation and Herbivory The effects of predators on prey and the effects of herbivores on plants are two very important density-dependent population controls. One classic study focuses on the relationship between wolves, moose, and plants on Isle Royale, an island in Lake Superior. The graph in **Figure 5–8** shows that populations of wolves and moose have fluctuated over the years. What drives these changes in population size?

▶ ***Predator-Prey Relationships*** In a predator-prey relationship, populations of predators and prey may cycle up and down over time. Sometimes, the moose population on Isle Royale grows large enough that moose become easy prey for wolves. When wolves have plenty to eat, their population grows. As the wolf population grows, the wolves begin to kill more moose than are born. This causes the moose death rate to rise higher than its birthrate, so the moose population falls. As the moose population drops, wolves begin to starve. Starvation raises the wolves' death rate and lowers their birthrate, so the wolf population also falls. When only a few predators are left, the moose death rate drops, and the cycle repeats.

In Your Notebook *Describe conditions that lead to competition in a population.*

Quick Lab
GUIDED INQUIRY

How Does Competition Affect Growth?

1. Label two paper cups 3 and 15. Make several small holes in the bottom of each cup. Fill each cup two-thirds full with potting soil. Plant 3 bean seeds in cup 3, and plant 15 bean seeds in cup 15.
2. Water both cups so that the soil is moist but not wet. Put them in a location that receives bright indirect light. Water the cups equally as needed.
3. Count the seedlings every other day for two weeks.

Analyze and Conclude

1. **Observe** What differences did you observe between the two cups?

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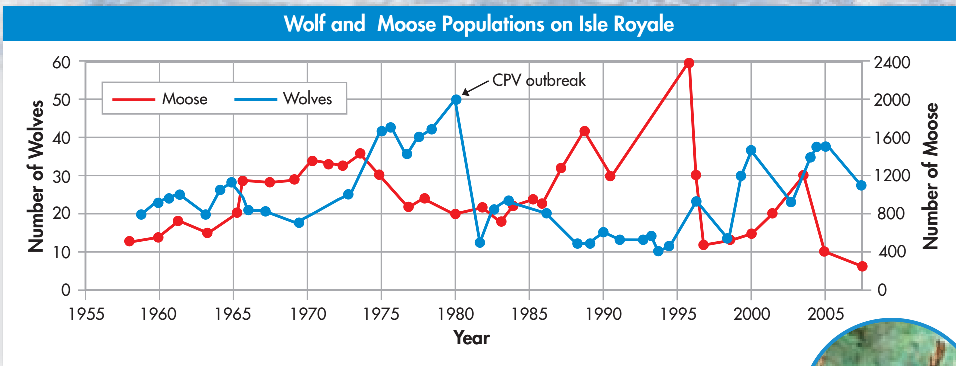


FIGURE 5–8 Moose-Wolf Populations on Isle Royale
The relationship between moose and wolves on Isle Royale illustrates how predation can affect population growth. In this case, the moose population was also affected by changes in food supply, and the wolf population was also impacted by a canine parvovirus (CPV) outbreak.

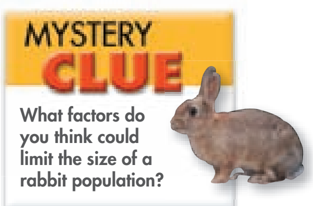
▶ ***Herbivore Effects*** Herbivory can also contribute to changes in population numbers. From a plant's perspective, herbivores are predators. So it isn't surprising that populations of herbivores and plants cycle up and down, just like populations of predators and prey. On parts of Isle Royale, large, dense moose populations can eat so much balsam fir that the population of these favorite food plants drops. When this happens, the moose may suffer from lack of food.

▶ ***Humans as Predators*** In some situations, human activity limits populations. For example, humans are major predators of codfish in New England. Fishing fleets, by catching more and more fish every year, have raised cod death rates so high that birthrates cannot keep up. As a result, the cod population has been dropping. Is there any way to solve the problem? Think of predator-prey interactions. The cod population can recover if we scale back fishing to lower the death rate sufficiently. Biologists are studying birthrates and the age structure of the cod population to determine how many fish can be taken without threatening the survival of the population.

BUILD Vocabulary

ACADEMIC WORDS The verb **fluctuate** means to "rise and fall as if in waves." A population that fluctuates is unstable: Its numbers go up and down irregularly.

FIGURE 5–9 Parasitism The ticks feeding on the blood of this hedgehog can transmit bacteria that cause disease.



Parasitism and Disease Parasites and disease-causing organisms feed at the expense of their hosts, weakening them and often causing disease or death. The ticks on the hedgehog in **Figure 5–9,** for example, can carry diseases. Parasitism and disease are density-dependent effects because the denser the host population, the more easily parasites can spread from one host to another.

If you look back at the graph in **Figure 5–8,** you can see a sudden and dramatic drop in the wolf population around 1980. At that time, a viral disease of wolves was accidentally introduced to the island. This virus killed all but 13 wolves on the island—and only three of the survivors were females. The removal of wolves caused moose populations to skyrocket to 2400. The densely packed moose then became infested with winter ticks that caused hair loss and weakness.

Stress From Overcrowding Some species fight amongst themselves if overcrowded. Too much fighting can cause high levels of stress, which can weaken the body's ability to resist disease. In some species, stress from overcrowding can cause females to neglect, kill, or even eat their own offspring. Thus, stress from overcrowding can lower birthrates, raise death rates, or both. It can also increase rates of emigration.

Density-Independent Limiting Factors

What limiting factors do not typically depend on population density?

Density-independent limiting factors affect all populations in similar ways, regardless of population size and density. **Unusual weather such as hurricanes, droughts, or floods, and natural disasters such as wildfires, can act as density-independent limiting factors.** In response to such factors, a population may "crash." After the crash, the population may build up again quickly, or it may stay low for some time.

For some species, storms can nearly extinguish local populations. For example, thrips, aphids, and other insects that feed on leaves can be washed out by a heavy rainstorm. Waves whipped up by hurricanes can devastate shallow coral reefs. Extremes of cold or hot weather also can take their toll, regardless of population density. A severe drought, for example, can kill off great numbers of fish in a river, as shown in **Figure 5–10.**

True Density Independence? Sometimes, however, the effects of so-called density-independent factors can actually vary with population density. On Isle Royale, for example, the moose population grew exponentially for a time after the wolf population crashed. Then, a bitterly cold winter with very heavy snowfall covered the plants that moose feed on, making it difficult for the moose to move around to find food.

Because this was an island population, emigration was not possible; the moose weakened and many died. So, in this case, the effects of bad weather on the large, dense population were greater than they would have been on a small population. (In a smaller population, the moose would have had more food available because there would have been less competition.) This situation shows that it is sometimes difficult to say that a limiting factor acts *only* in a density-independent way.

Human activities can also place ecological communities under stress in ways that can hamper a population's ability to recover from natural disturbance. You will learn more about that situation in the next chapter.

Controlling Introduced Species In hydrilla's natural environment, density-dependent population limiting factors keep it under control. Perhaps plant-eating insects or fishes devour it. Or perhaps pests or diseases weaken it. Whatever the case, those limiting factors are not found in the United States. The result is runaway population growth!

Efforts at artificial density-independent control measures—such as herbicides and mechanical removal—offer only temporary solutions and are expensive. Researchers have spent decades looking for natural predators and pests of hydrilla. The best means of control so far seems to be an imported fish called grass carp, which view hydrilla as an especially tasty treat. These grass carp are not native to the United States. Only sterilized grass carp can be used to control hydrilla. Can you understand why?

FIGURE 5–10 Effects of a Severe Drought on a Population Dead fish lie rotting on the banks of the once-flowing Paraná de Manaquiri River in Brazil.

5.2 Assessment

Review Key Concepts

1. a. Review What is a limiting factor?

b. Apply Concepts How do limiting factors affect the growth of populations?

2. a. Review List three density-dependent limiting factors.

b. Relate Cause and Effect What is the relationship between competition and population size?

3. a. Review What is a density-independent limiting factor?

b. Apply Concepts Give three examples of density-independent factors that could severely limit the growth of a population of bats living in a cave.

Apply the Big idea

Interdependence in Nature

4. Study the factors that limit population growth shown in **Figure 5–6.** Classify each factor as biotic or abiotic. (*Hint:* Refer to Lesson 3.1 for information on biotic and abiotic factors.)

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5.3 Human Population Growth

Key Questions

How has human population size changed over time?

Why do population growth rates differ among countries?

Vocabulary

demography
demographic transition

Taking Notes

Preview Visuals Before you read, preview the graphs in **Figures 5–11, 5–12,** and **5–13.** Make a list of questions about the graphs. Then, as you read, write down the answers to your questions.

THINK ABOUT IT How quickly is the global human population growing? In the United States and other developed countries, the population growth rate is low. But in some developing countries, the population is growing very rapidly. Worldwide, there are more than four human births every second. At this birthrate, the human population is well on its way to reaching 9 billion in your lifetime. What do the present and future of human population growth mean for our species and its interactions with the rest of the biosphere?

Historical Overview

How has human population size changed over time?

The human population, like populations of other organisms, tends to increase. The rate of that increase has changed dramatically over time. For most of human existence, the population grew slowly because life was harsh. Food was hard to find. Predators and diseases were common and life-threatening. These limiting factors kept human death rates very high. Until fairly recently, only half the children in the world survived to adulthood. Because death rates were so high, families had many children, just to make sure that some would survive.

BUILD Vocabulary

ACADEMIC WORDS The adverb **dramatically** means "forcefully" or "significantly." When something is described as having changed dramatically, it means it has changed in a striking way.

Exponential Human Population Growth As civilization advanced, life became easier, and the human population began to grow more rapidly. That trend continued through the Industrial Revolution in the 1800s. Food supplies became more reliable, and essential goods could be shipped around the globe. Several factors, including improved nutrition, sanitation, medicine, and healthcare, dramatically reduced death rates. Yet, birthrates in most parts of the world remained high. The combination of lower death rates and high birthrates led to exponential growth, as shown in **Figure 5–11.**

The Predictions of Malthus As you've learned, this kind of exponential growth cannot continue forever. Two centuries ago, this problem troubled English economist Thomas Malthus. Malthus suggested that only war, famine, and disease could limit human population growth. Can you see what Malthus was suggesting? He thought that human populations would be regulated by competition (war), limited resources (famine), parasitism (disease), and other density-dependent factors. Malthus's work was vitally important to the thinking of Charles Darwin.

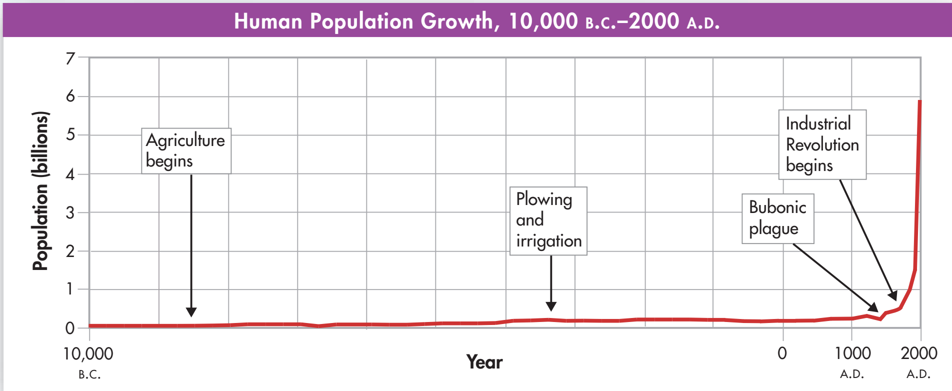
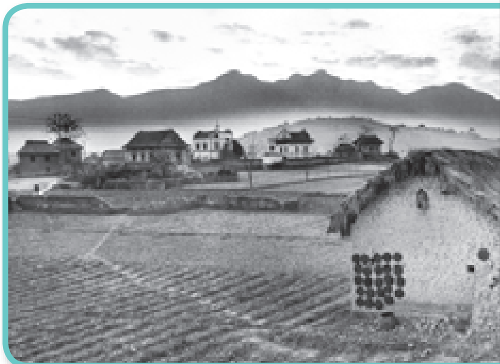
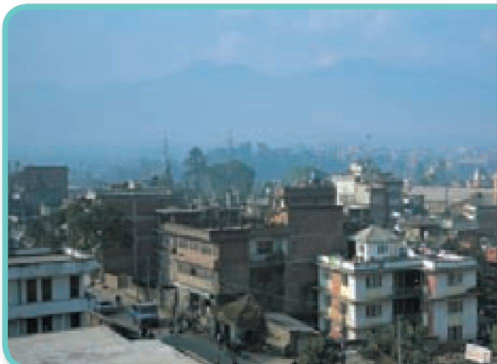


FIGURE 5–11 Human Population Growth Over Time After a slow start, the human population grew exponentially following advances in civilization. Change can be dramatic; these photos of Katmandu, Nepal, were taken from the same position in 1969 and 1999—just 30 years apart!





World Population Growth Slows So what is happening to human population growth today? Exponential growth continued up to the second half of the twentieth century. The human population growth rate reached a peak around 1962–1963, and then it began to drop. The size of the global human population is still growing rapidly, but the rate of growth is slowing down.

It took 123 years for the human population to double from 1 billion in 1804 to 2 billion in 1927. Then it took just 33 years for it to grow by another billion people. The time it took for the population to increase each additional billion continued to fall until 1999, when it began, very slowly, to rise. It now takes longer for the global human population to grow by 1 billion than it did 20 years ago. What has been going on?

Patterns of Human Population Growth

Why do population growth rates differ among countries?

Scientists have identified several social and economic factors that affect human population growth. The scientific study of human populations is called **demography.** Demography examines characteristics of human populations and attempts to explain how those populations will change over time. **Birthrates, death rates, and the age structure of a population help predict why some countries have high growth rates while other countries grow more slowly.**

In Your Notebook *Explain how the size of the global human population can increase while the rate of growth decreases.*

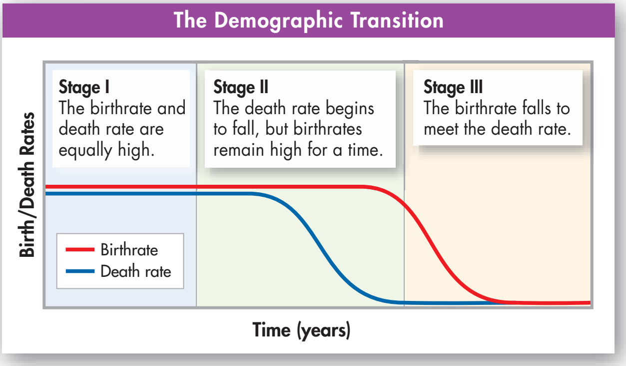
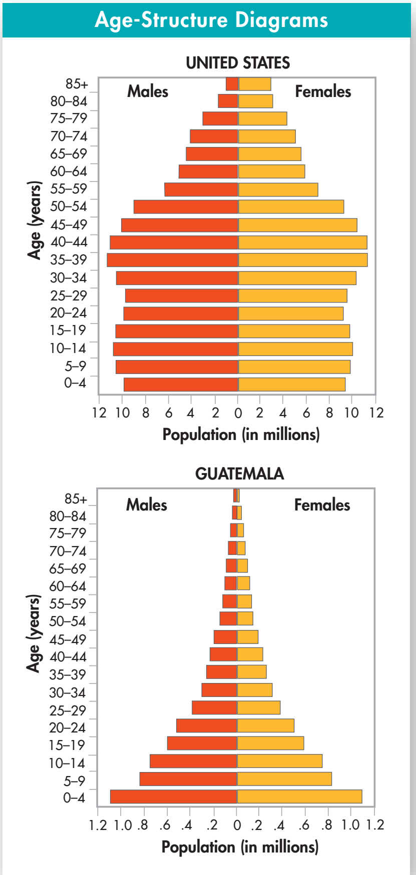


FIGURE 5–12 The Demographic Transition Human birthrates and death rates are high for most of history (Stage I). Advances in nutrition, sanitation, and medicine lead to lower death rates. Birthrates remain high for a time, so births greatly exceed deaths (Stage II), and the population increases exponentially. As levels of education and living standards rise, families have fewer children and the birthrate falls (Stage III), and population growth slows. The demographic transition is complete when the birthrate meets the death rate, and population growth stops.

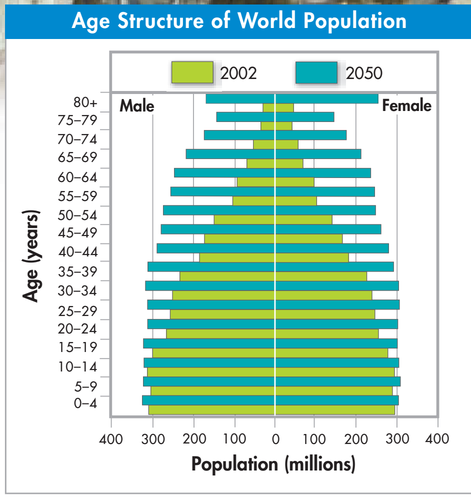


The Demographic Transition Human societies had equally high birthrates and death rates during most of history. But over the past century, population growth in the United States, Japan, and much of Europe slowed dramatically. Demographers developed a hypothesis to explain this shift. According to this hypothesis, these countries have completed the **demographic transition,** a dramatic change from high birthrates and death rates to low birthrates and death rates. The demographic transition is divided into three stages, as shown in **Figure 5–12.**

To date, the United States, Japan, and Europe have completed the demographic transition. Parts of South America, Africa, and Asia are passing through Stage II. (The United States passed through Stage II between 1790 and 1910.) A large part of ongoing human population growth is happening in only ten countries, with India and China in the lead. Globally, human population is still growing rapidly, but the rate of growth is slowing down. Our J-shaped growth curve may be changing into a logistic growth curve.

Age Structure and Population Growth To understand population growth in different countries, we turn to age-structure diagrams. **Figure 5–13** compares the age structure of the U.S. population with that of Guatemala, a country in Central America. In the United States, there are nearly equal numbers of people in each age group. This age structure predicts a slow but steady growth rate for the near future. In Guatemala, on the other hand, there are many more young children than teenagers, and many more teenagers than adults. This age structure predicts a population that will double in about 30 years.

FIGURE 5–13 Comparison of Age Structures These diagrams compare the populations of the United States and Guatemala. Notice the difference in their *x*-axis scales. **Analyze Data** ***How do the two countries differ in the percentages of 10–14-year-olds in their populations?***



Future Population Growth To predict how the world's human population will grow, demographers consider many factors, including the age structure of each country and the effects of diseases on death rates—especially AIDS in Africa and parts of Asia. Current projections suggest that by 2050 the world population will reach 9 billion people. Will the human population level out to a logistic growth curve and become stable? This may happen if countries that are currently growing rapidly complete the demographic transition.

Current data suggest that global human population will grow more slowly over the next 50 years than it grew over the last 50 years. But because the growth rate will still be higher than zero in 2050, our population will continue to grow. In the next chapter, we will examine the effect of human population growth on the biosphere.

FIGURE 5–14 A Growing Population This graph (from the U.S. Census Bureau, International Database) shows the projected age structure of the world population in 2050. As population numbers climb, cities face various challenges, such as housing. The photo above shows a housing complex in Hong Kong; each apartment building is home to thousands of residents.

5.3 Assessment

Review Key Concepts

1. a. **Review** Describe the general trend of human population growth over time.
   b. **Relate Cause and Effect** What factors contributed to the pattern of growth shown in **Figure 5–11**?
2. a. **Review** Why do populations in different countries grow at different rates?
   b. **Explain** Describe the demographic transition and explain how it could affect a country's population growth rate.
   c. **Form an Opinion** Are age-structure diagrams useful in predicting future population trends?

VISUAL THINKING

3. Describe the changes in human population predicted by **Figure 5–14.** How do you think those changes will affect society?

Skills Lab

GUIDED INQUIRY

Pre-Lab: The Growth Cycle of Yeast

Problem What type of population growth occurs in a yeast culture?

Materials yeast culture, stirring rod, dropper pipettes, microscope slides, coverslips, microscope, 10-mL graduated cylinder, test tubes, test-tube rack, graph paper

Lab Manual Chapter 5 Lab

Skills Measure, Calculate, Interpret Graphs

Connect to the Big idea Populations depend on, and are limited by, their environments. A population can grow when its members have the resources they need to survive and reproduce. Factors that can limit those resources include natural disasters, such as forest fires, and competition from other species. Predation and disease are also limiting factors for populations.

In nature, populations often experience cycles of growth and decline. In this lab, you will investigate whether such a cycle occurs in yeast populations.

Background Questions

a. **Review** What is the carrying capacity of a population?

b. **Sequence** Briefly describe the three phases of logistic growth.

c. **Relate Cause and Effect** Describe two different ways that a population might achieve a growth rate of zero.

d. **Classify** After two weeks of hot and sunny days with very little rain, the blades of grass in a backyard began to wither and die. Were any of the factors that caused the decline of the grass population dependent on density? Explain.

Pre-Lab Questions

Preview the procedure in the lab manual.

1. **Infer** Why was grape juice used to prepare the yeast cultures instead of plain water?

2. **Form a Hypothesis** Why will you locate the yeast cells under low power, but switch to high power to count the cells?

3. **Calculate** Suppose you have to do one dilution of your culture before you are able to count the yeast cells. If you count 21 yeast cells in the diluted sample, how many yeast cells were in the same area of the undiluted sample? MATH

4. **Predict** What do you think will happen to a yeast population between Day 3 and Day 7? Give reasons for your answer.

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Visit Chapter 5 online to test yourself on chapter content and to find activities to help you learn.

Untamed Science Join the Untamed Science crew as they learn the latest techniques for counting populations.

Art in Motion View a short animation that brings age-structure diagrams to life.

Art Review Review your understanding of limiting factors with this drag-and-drop activity.

InterActive Art Manipulate factors such as starting population size, birthrate, and death rate to see how they would impact moose and wolf populations over time.

Data Analysis Analyze logistic growth curves in order to make predictions about zebra mussel growth.

5 Study Guide

Big idea Interdependence in Nature

The way a population changes depends on many things, including its age structure, the rates at which individuals are added or removed from the population, and factors in the environment that limit its growth.

5.1 How Populations Grow

Researchers study populations' geographic range, density and distribution, growth rate, and age structure.

The factors that can affect population size are the birthrate, the death rate, and the rate at which individuals enter or leave the population.

Under ideal conditions with unlimited resources, a population will grow exponentially.

Logistic growth occurs when a population's growth slows and then stops, following a period of exponential growth.

population density (131)
age structure (131)
immigration (132)
emigration (132)
exponential growth (132)
logistic growth (135)
carrying capacity (135)

5.2 Limits to Growth

Acting separately or together, limiting factors determine the carrying capacity of an environment for a species.

Density-dependent limiting factors operate strongly when population density reaches a certain level. Density-dependent limiting factors include competition, predation, herbivory, parasitism, disease, and stress from overcrowding.

Density-independent limiting factors affect all populations in similar ways, regardless of population size and density. Unusual weather such as hurricanes, droughts, or floods, and natural disasters such as wild-fires, can act as density-independent limiting factors.

limiting factor (137)
density-dependent limiting factor (138)
density-independent limiting factor (140)

5.3 Human Population Growth

The human population, like populations of other organisms, tends to increase. The rate of that increase has changed dramatically over time.

Birthrates, death rates, and the age structure of a population help predict why some countries have high growth rates while other countries grow more slowly.

demography (143)
demographic transition (144)

Think Visually Create a table in which you describe the phases of logistic growth.

5 Assessment

5.1 How Populations Grow

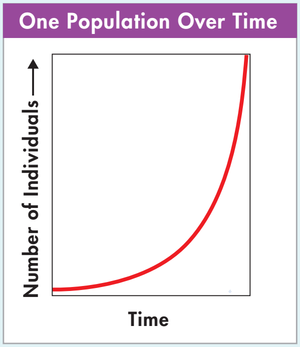
Understand Key Concepts

1. The number of individuals of a single species per unit area is known as
   a. carrying capacity.
   b. logistic growth.
   c. population density.
   d. population growth rate.

2. The movement of individuals into an area is called
   a. demography.
   b. carrying capacity.
   c. immigration.
   d. emigration.

3. The area inhabited by a population is known as its
   a. growth rate.
   b. geographic range.
   c. age structure.
   d. population density.

4. The graph below represents
   a. carrying capacity.
   b. exponential growth.
   c. logistic growth.
   d. age structure.



5. The maximum number of organisms of a particular species that can be supported by an environment is called
   a. logistic growth.
   b. carrying capacity.
   c. exponential growth.
   d. population density.

6. What is the difference between immigration and emigration?

7. Sketch the exponential growth curve of a hypothetical population.

8. Describe the conditions under which logistic growth occurs.

9. What is carrying capacity? Give an example.

Think Critically

10. **Use Analogies** How is the carrying capacity of a city's roads similar to the carrying capacity of an ecosystem?

5.2 Limits to Growth

Understand Key Concepts

11. A limiting factor that depends on population size is called a
    a. density-dependent limiting factor.
    b. density-independent limiting factor.
    c. predator-prey relationship.
    d. parasitic relationship.

12. One example of a density-independent limiting factor is
    a. predation.
    b. hurricanes.
    c. competition.
    d. parasitism.

13. How might increasing the amount of a limiting nutrient in a pond affect the carrying capacity of the pond?

14. Describe the long-term effects of competition on populations of two different species competing for the same resources.

15. Describe how a predator-prey relationship can control both the predator population and the prey population.

16. How do parasites serve as a density-dependent limiting factor?

Think Critically

17. **Predict** What would happen to a population of predators if there was a sudden increase in food for the prey? Explain your answer.

18. **Apply Concepts** Why would a contagious virus that causes a fatal disease be considered a density-dependent limiting factor?

19. **Infer** Would a density-independent limiting factor have more of an effect on population size in a large ecosystem or in a small ecosystem?

20. **Compare and Contrast** How is the relationship between parasites and their hosts similar to a predator-prey relationship?

21. **Apply Concepts** How would a drop in the water level of a river affect a fish population living in that river?

5.3 Human Population Growth

Understand Key Concepts

22. The scientific study of human populations is called
    a. immigration.
    b. emigration.
    c. demographic transition.
    d. demography.

23. The demographic transition is considered complete when
    a. population growth stops.
    b. the birthrate is greater than the death rate.
    c. the death rate begins to fall.
    d. the death rate is greater than the birthrate.

24. How can you account for the fact that the human population has grown more rapidly during the past 500 years than it has at any other time in history?

25. What is the significance of the demographic transition in studies of human population around the world?

26. How does the age structure of a population affect its growth rate?

27. What factors did Thomas Malthus think would eventually limit the human population?

Think Critically

28. **Compare and Contrast** What shape population growth curve would you expect to see in a small town made up mainly of senior citizens? Compare this growth curve to that of a small town made up of newly married couples in their twenties.

29. **Pose Questions** What questions would a demographer need to answer to determine whether a country is approaching the demographic transition?

solve the CHAPTER MYSTERY

A PLAGUE OF RABBITS

Australia had no native rabbit population when the European rabbits arrived, so there were no density-dependent controls to keep their numbers in check. The rabbits' new environment provided many favorable conditions for survival, including fewer predators, parasites, and diseases. The initial small number of rabbits—which can reproduce rapidly—soon multiplied into millions.

High rabbit numbers caused serious environmental and agricultural damage. In an effort to manage the problem, many methods have been tried, including fencing, poisoning, the destruction of burrows, and the use of parasites and disease. In the 1950s, a rabbit virus that causes the fatal rabbit disease myxomatosis was deliberately introduced as a form of biological control. It killed countless rabbits. But the virus and rabbits soon reached an equilibrium that allowed host and parasite to coexist, and the rabbit population rose. Later, a new virus that causes rabbit hemorrhagic disease (RHD) was introduced, and the rabbit population dropped again. In several places, environmental recovery was dramatic: Native animals recovered, and native trees and shrubs thought to be locally extinct began to grow again. But the RHD virus and rabbits appear to have reached a new balance, and the rabbit population is rising again!

1. **Predict** Populations of wildcats and foxes (both also introduced to Australia) have come to depend on rabbits as prey. How do you think wildcats and foxes would be affected by a crash in the rabbit population?

2. **Connect to the Big idea** Why should people be cautious about introducing organisms into new environments?

Connecting Concepts

Use Science Graphics

The following actual and projected data, from the United Nations Department of Economic and Social Affairs, Population Division, show when the global population reached or will reach an additional billion. Use the data table to answer questions 30 and 31.

World Population Milestones

Population (billion)	Year	Time Interval (years)
1	1804	—
2	1927	123
3	1960	33
4	1974	14
5	1987	13
6	1999	12
7	2012	13
8	2027	15
8.9	2050	23

30. Observe When did the world population reach 1 billion people? When did it reach 6 billion?

31. Interpret Tables Describe the trend in population growth since the 1-billion-people mark.

Write About Science

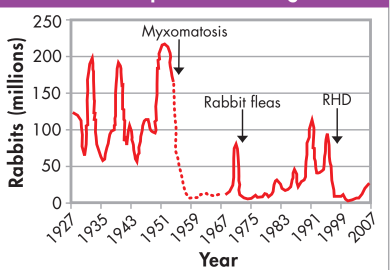
32. Explanation Write a paragraph on the human population. Include the characteristics of a population, factors that affect its size, and changes in the size of the population from about 500 years ago to the present. Give a projection of how large the world population might be in the year 2050 and of how the growth rate in 2050 might compare to that in 2000. (*Hint*: Outline your ideas before you begin to write.)

33. Assess the Big idea Choose a specific organism and explain how the population of that organism depends on a number of factors that may cause it to increase, decrease, or remain stable in size.

Analyzing Data

The following graph shows the "boom-and-bust" pattern of regular rises and falls in the rabbit population in South Australia. The points at which various population control measures were introduced are indicated. Use the graph to answer questions 34 and 35.

Rabbit Population Changes



34. Interpret Graphs In which of the following years was the rabbit population density in South Australia most dense?

a. 1936
b. 1952
c. 1975
d. 2000

35. Infer European rabbit fleas were introduced in the late 1960s to help spread the effects of the rabbit disease myxomatosis. Based on the graph, what can you infer about the rabbit population after the fleas were introduced?

a. The rabbit birthrate increased.
b. The rabbit death rate increased.
c. The rabbit death rate decreased.
d. The fleas had no effect on the rabbit population.

Standardized Test Prep

Multiple Choice

1. The movement of individuals into an area is called
A immigration.
B emigration.
C population growth rate.
D population density.

2. All other things being equal, the size of a population will decrease if
A birthrate exceeds the death rate.
B immigration rate exceeds emigration rate.
C death rate exceeds birthrate.
D birthrate equals death rate.

3. Which of the following is NOT an example of a density-dependent limiting factor?
A natural disaster
B predator
C competition
D disease

4. A population like that of the United States with an age structure of roughly equal numbers in each of the age groups can be predicted to
A grow rapidly over a 30-year-period and then stabilize.
B grow little for a generation and then grow rapidly.
C fall slowly and steadily over many decades.
D show slow and steady growth for some time into the future.

5. In the presence of unlimited resources and in the absence of disease and predation, what would probably happen to a bacterial population?
A logistic growth
B exponential growth
C endangerment
D extinction

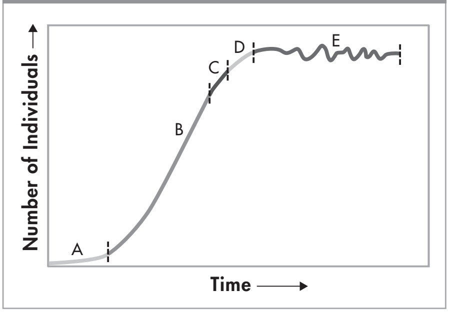
6. Which of the following statements best describes human population growth?
A The growth rate has remained constant over time.
B Growth continues to increase at the same rate.
C Growth has been exponential in the last few hundred years.
D Birthrate equals death rate.

7. Which of the following refers to when a population's birthrate equals its death rate?
A limiting factor
B carrying capacity
C exponential growth
D population density

Questions 8–9

Use the graph below to answer the following questions.

Logistic Growth



8. Which time interval(s) in the graph shows exponential growth?
A D and E
B A and B
C C and D
D E only

9. Which time interval(s) in the graph depicts the effects of limiting factors on the population?
A A only
B A and B
C C, D, and E
D C and D

Open-Ended Response

10. When a nonnative species is imported into a new ecosystem, the population sometimes runs wild. Explain why this might be the case.

If You Have Trouble With . . .

Question	1	2	3	4	5	6	7	8	9	10
See Lesson	5.1	5.1	5.2	5.3	5.1	5.3	5.1	5.1	5.2	5.2