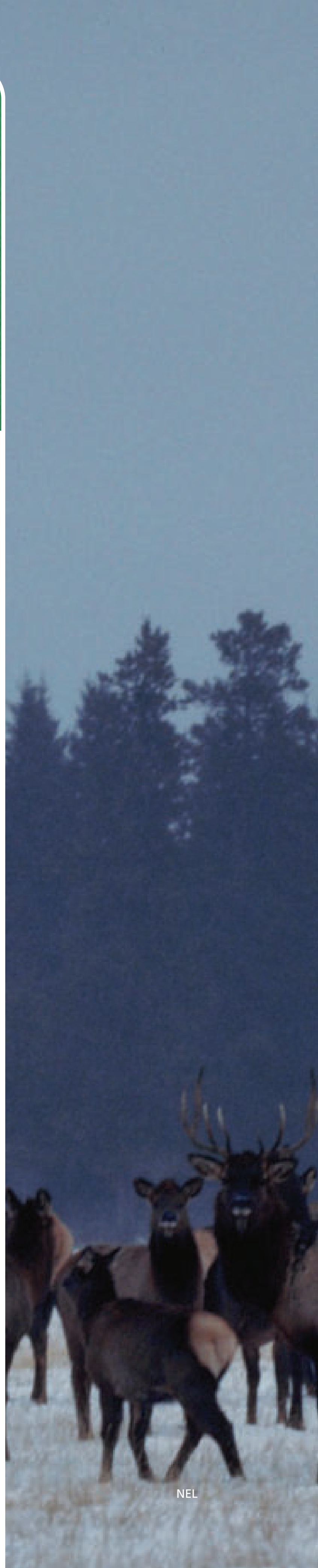
unit

30 D

Population and Community Dynamics



Populations are the functioning units of individual species. Individuals within a population vary due to their genetic diversity and the demands of their environment, and interact with each other in many ways. Many populations together make up an ecological community, in which each population interacts with the others. These interactions, rather than the individuals or species themselves, provide both stability and the potential for dynamic change in the ecosystem. In many ecosystems, such as in the boreal forest shown here, the biotic and abiotic components of the environment vary with the seasons. Population ecologists document and interpret the interactions, quantifying the changes that occur over time.

In this unit, you will gain an understanding of the variety of interactions both within populations and among the populations in a community. You will use this understanding to examine the very successful growth of our own species and our changing relationships with the other organisms on Earth.

As you progress through the unit, think about these focusing questions:

- How does one determine if populations are changing over time?
- In what ways may individual members of a population interact with one another or with members of a different population?
- What quantitative measures indicate that populations change over time?

UNIT 30 D PERFORMANCE TASK

Changes in Human Population Size

The United Nations estimates that the global human population is greater than 6 billion people. About 100 000 years ago, only a few thousand people lived on Earth. What factors contributed to this growth? How did humans become such a successful species? At the end of this unit, you may apply your skills and knowledge to complete this Performance Task.

GENERAL OUTCOMES

In this unit, you will

- describe a community as a composite of populations in which individuals contribute to a gene pool that can change over time
- explain the interaction of individuals in populations with each other and with members of other populations, the basis of which is genetic variation
- explain, in quantitative terms, the changes in populations over time

Unit 30 D

Population and Community Dynamics

ARE YOU READY?

Prerequisites

Concepts

- resource limits of an ecosystem
- roles of meiosis, mitosis, DNA, genes, alleles
- relationship between genotypes, phenotypes, and the environment
- types of mutations
- role of genetic recombination including crossing over

Skills

- analyze a population study using Punnett squares
- apply an understanding of inheritance
- relate an understanding of biological diversity to genetic diversity

You can review prerequisite concepts and skills on the Nelson Web site and in the Appendices.

A Unit Pre-Test is also available online.

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These questions will help you find out what you already know, and what you need to review, before you continue with this unit.

Knowledge

1. In your notebook, indicate whether the statement is true or false. Rewrite a false statement to make it true.
   (a) Mutations are changes in DNA that are harmful to the cell.
   (b) Sexual reproduction is disadvantageous because the offspring show little or no genetic diversity.
   (c) Through the process of genetic recombination, meiosis produces diploid cells and increases the potential diversity of offspring.
   (d) In species that reproduce asexually, offspring are always genetically identical to their parent.
   (e) Over time, dominant alleles will tend to become more common in a population, while recessive alleles will become more rare.
   (f) An organism's genotype refers to its genetic makeup, which is unaffected by the environment.
   (g) An organism's phenotype refers to traits that are expressed in the organism and affected by both its genotype and the environment.
   (h) A species is a population or populations of organisms that are able to interbreed under natural conditions and produce fertile offspring.
   (i) Harmful or lethal mutations have little or no effect on the health of large multicellular organisms.
   (j) Virtually all large populations exhibit genetic variation among individuals.

2. Define these terms:
   (a) exotic species
   (b) carrying capacity
   (c) food chain
   (d) food web
   (e) biotic factors
   (f) abiotic factors

3. **Figure 1** shows four steps in meiosis that contribute to genetic recombination. Explain what event is occurring in each step, and how each step contributes to increased genetic variation of gametes.

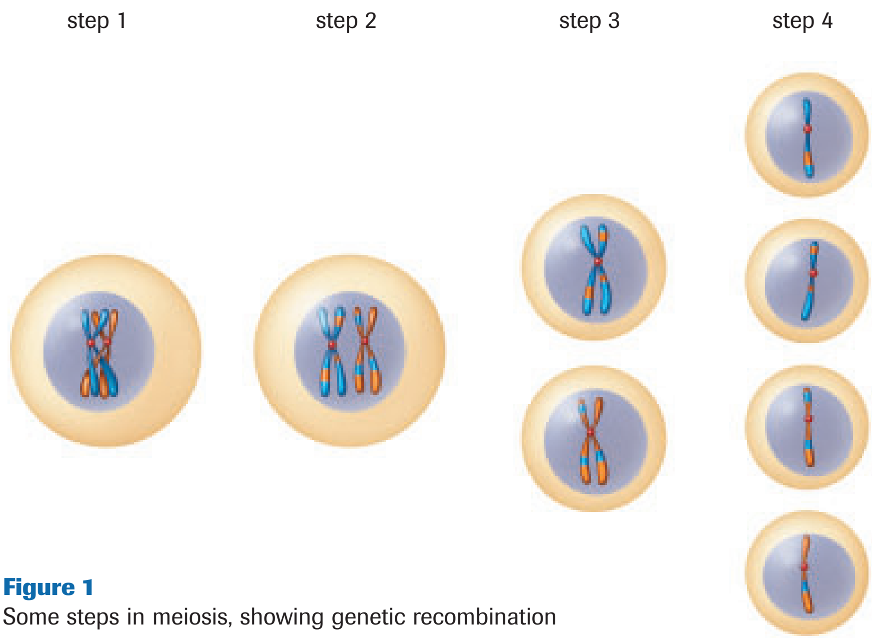


Figure 1
Some steps in meiosis, showing genetic recombination

Skills

4. Examine the Punnett square in **Figure 2**, which represents a cross between a male that is homozygous for two dominant alleles, *AA* and *HH*, and a female that is homozygous for two recessive alleles, *aa* and *hh*.
   (a) Have the variety and ratio of genotypes changed in the F_1 generation?
   (b) In the parent generation, state the ratio of the specific alleles for each gene (i.e., *A*:*a* and *H*:*h*).
   (c) Taking all F_1 individuals into consideration, do the allele ratios change in the F_1 generation? Explain your reasoning.
   (d) Draw a Punnett square and determine the allele ratios for the F_2 generation.

gametes → ↓	*ah*	*ah*
AH	*AaHh*	*AaHh*
AH	*AaHh*	*AaHh*

Figure 2
Punnett square analysis of a dihybid cross

5. Zebra mussels often grow in high concentrations on water intake pipes. Assume that **Table 1** represents the number of mussels per square metre of pipe surface sampled over a 10-year period.

Table 1 Zebra Mussel Population in a Small Water Body, 1991–2000

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Population (per m^2)	400	520	676	879	1142	1485	1930	2509	3262	4241

   (a) Draw a population curve for the zebra mussel population from 1991 to 2000. Label your axes, and give your graph an appropriate title.
   (b) Describe the growth illustrated by your graph.
   (c) Calculate the population growth rate of zebra mussels from 1996 to 2000.
   (d) If no measures are taken to control the zebra mussel population in this location, hypothesize what the population would be in 2010. Add these data to your graph.
   (e) What factors are likely to limit the growth of this zebra mussel population?

STS Connections

6. For each of the following, list two examples, one that is not genetically inherited and one that might have been genetically inherited:
   (a) physical characteristics
   (b) diseases and medical conditions
   (c) behaviours, and likes and dislikes

7. Zebra mussels clog pipelines and other underwater structures (**Figure 3**). What economic and other social impacts could this problem cause?

Figure 3
Zebra mussels

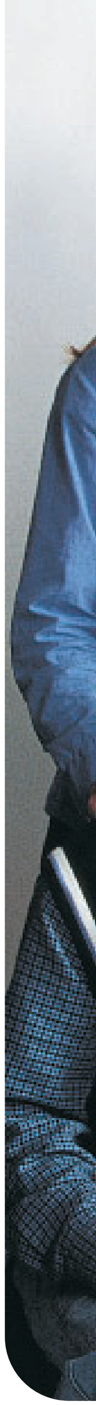
8. In January 2002, the North American Commission for Environmental Cooperation released a report that declared that North America is facing a "widespread crisis" because of its shrinking biodiversity.
   (a) How is the loss of biodiversity related to the loss of genetic diversity?
   (b) Why do so many scientists, government agencies, and members of the public consider it an important issue?

chapter

21 The Genetic Basis for Population Change

In this chapter

We have all noticed that certain traits are inherited from generation to generation (**Figure 1**). In *On the Origin of Species,* Charles Darwin provided compelling evidence for evolution and natural selection. About 70 years after Darwin's work, scientists finally understood how parents' traits are inherited by offspring. Now, geneticists can distinguish the genetic code of one individual from those of a whole population. This powerful science is also being used to measure the genetic differences between entire species and to document changes in the genetic makeup of populations over surprisingly short periods of time.



STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Successful individuals of a species are able to reproduce and adapt to their environments. What role might their genetic makeup play in meeting these two demands?
2. The population size of marine green sea turtles (**Figure 2 (a)**) shows little change over time while the locust population in the Canadian prairies (**Figure 2 (b)**) varies widely from year to year. What might this suggest about the environments in which they live? Which environment is the most stable?

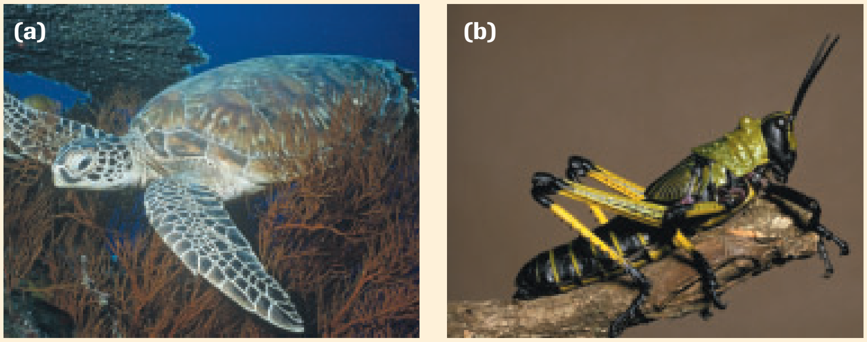


Figure 2
(a) green sea turtle
(b) locust

Career Connections:
University Professor; Anthropologist

Figure 1
Although individuals in a population have some unique traits, other traits are common to all the members.

Exploration — *Distinguishing Traits*

Study the photo of the group of people in **Figure 1**. These individuals exhibit variations, but they also share such inherited physical features as limbs, internal organs, and paired eyes and ears. Yet pigeons, alligators, horses, and toads also possess these features.

(a) List inheritable features by which you can distinguish human beings from all other species.

(b) List inheritable features by which you can distinguish human individuals from one another.

(c) On each list, circle the two or three most significant distinguishing traits.

(d) Are the most distinguishing traits from parts (a) and (b) unique to each species and individual respectively, or do they represent variations of shared features?

21.1 The Hardy–Weinberg Principle

Figure 1
The genetic diversity of many populations, such as this one of long-nosed bats, may not be readily apparent.

Recall from Unit 30 C that all individuals of the same species possess a common genome, except for sex chromosomes (when present). However, each individual has a different genotype. Differences in genotypes and environmental influences account for differences among the phenotypes of individuals of the same species. These different phenotypes are then acted on by natural selection.

Traits that distinguish individuals from one another represent genetic diversity, which varies both within species and from species to species (**Figure 1**).

With techniques such as DNA sequencing, geneticists have begun to analyze and compare the genetic code of individuals, populations, and entire species. One finding is that the amount of DNA present in different species varies dramatically, as shown by the examples in **Table 1**. Organisms with larger genomes have the potential for greater genetic diversity and present more targets for mutation.

The size of genomes, however, does not provide an accurate comparison of a species' genetic diversity. Genomes of many eukaryotic organisms, for example, contain DNA that is not transcribed. Some noncoding sequences in the genome of humans, as well as other organisms, may be repeated as many as 500 000 times. Some species, such as maize or wheat, are polyploids. This means that the species has more than two copies of each chromosome, resulting in multiple, often identical, copies of the same genes.

Regardless of the total quantity of DNA present, most species (other than some microorganisms) have large numbers of different genes—usually numbering in the thousands. Species that possess a larger number of genes have the potential for increased genetic diversity. Similarly, the greater the number of different alleles for these genes, the more genetic variation there will be between individuals in a species. For species that undergo sexual reproduction, genetic diversity within a population increases enormously when the various alleles from two parents recombine at fertilization.

As you learned in Chapter 6, all of the genes that occur in a population are referred to as the gene pool. The gene pool maintains continuity of traits from generation to generation. Although some gene frequencies remain the same over many generations, others change quickly.

CAREER CONNECTION

University Professor
University professors conduct and publish new research, increasing the body of scientific knowledge in the world. They also teach post-secondary students and supervise and develop research programs. University professors are able to follow their passions and study whatever they find the most interesting. If you are interested in exploring new areas of scientific discovery and enjoy teaching, find out more information on becoming a university professor.

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Table 1 Total Amount of DNA in the Genomes of Selected Species

Species	Common name	DNA (kilobases)
Mycoplasma genetalium	bacterium	580
Saccharomyces cerevisiae	yeast	1200
Drosophila melanogaster	fruit fly	180 000
Xenopus laevis	toad	3 100 000
Macaca nigra	macaque	3 399 900
Homo sapiens	human	3 400 000
Necturus maculosus	mud puppy	81 300 000
Amphiuma means	newt	84 000 000
Trillium species	trillium	100 000 000
Amoeba dubia	amoeba	670 000 000

WEB Activity

Case Study—Global Variation in Blood Type

Blood type is an inherited characteristic. Each individual has type A, B, AB, or O blood, and also either Rh negative (Rh–) or Rh positive (Rh+). The alleles responsible for these blood types are designated as I^A, I^B, I^O, *Rh+*, and *Rh–*.

Your ABO blood type was determined by the direct inheritance of one allele from each of your parents; it cannot be altered by any environmental factor. As a result, blood types are ideally suited for the study of human genetic variation and provide dramatic evidence of human genetic diversity at the population level.

In this activity, you will examine the geographic distribution of different blood types in humans. You will analyze these patterns and relate them to human genetic diversity, and use your understanding of genetics and populations to account for the distribution patterns.

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EXPLORE an issue

Are Human "Races" Only Skin Deep?

The geographic distribution patterns of blood alleles is not the same as the distribution patterns of skin colour and "race." This means that skin colours and blood types do not evolve in the same way. Thus, the whole notion of categorizing humans into "races" may be in error. Research the following and discuss your answers in a small group.

(a) How do we identify human "races"?

(b) What human skin colours are associated with what major landmasses?

(c) What environmental factor(s) are most likely responsible for the distribution of alleles that influence skin colour?

(d) A scientist proposes that governments define an individual's "race" according to his or her "blood type." The scientist argues that blood type is a much better indicator of human "relatedness" than skin colour.

(i) Is the scientist's argument valid? Is blood type more biologically significant than skin colour?

(ii) Is the concept of human "race" scientifically valid at all? Is it reasonable to group people according to a small genetic difference simply because it is visible?

Issue Checklist

- ○ Issue
- ● Resolution
- ● Design
- ● Evidence
- ● Analysis
- ● Evaluation

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Hardy–Weinberg Principle and Population Equilibrium

Population geneticists have developed a method to quantify a gene pool—the genetic information of an entire population—by measuring each **allele frequency**. Thus, changes in populations can be measured in part by looking for changes in allele frequencies. Note that not all genes exhibit variation. Where only a single allele exists for a particular gene, that allele's frequency is 100 % and it is described as a **fixed frequency**.

Consider a population of moths for which there are two alleles, *A* and *a*, where *A* represents the allele for dark brown wings, which is dominant, and *a* represents the allele for light brown wings, which is recessive. A population of 500 comprises 320 moths with *AA* homozygous dark wings, 160 moths with *Aa* heterozygous dark wings, and 20 moths with *aa* homozygous light brown wings. Each individual contributes two alleles to the gene pool, giving 640 *A* (from *AA* genotype), 160 *A* + 160 *a* (from *Aa* genotype), and 40 *a* (from *aa* genotype).

allele frequency the proportion of gene copies in a population of a given allele

fixed frequency the frequency of an allele within a population when only a single allele is present for a particular gene (i.e., the allele's frequency is 100 %)

Learning Tip

An allele is one of several forms of the same gene. For example, the gene for wing colour in **Figure 2** has two alleles: dark brown and light brown.

Genetic structure of parent population

phenotypes

genotypes	*AA*	*Aa*	*aa*
number of moths (total = 500)	320	160	20
genotype frequencies	$\frac{320}{500} = 0.64\ AA$	$\frac{160}{500} = 0.32\ Aa$	$\frac{20}{500} = 0.04\ aa$

× 2 (*AA*) · *Aa* splits to *A* and *a* · × 2 (*aa*)

number of alleles in gene pool (total = 1000)	640 *A*	160 *A*	160 *a*	40 *a*

allele frequencies	$\frac{800}{1000} = 0.8\ A$	$\frac{200}{1000} = 0.2\ a$
	p = frequency of *A* = 0.8	q = frequency of a = 0.2

Figure 2
The allele frequencies of a population of moths

The allele frequency for *A* is 800 ÷ 1000 = 0.80, or 80 %, and that of *a* is 200 ÷ 1000 = 0.20, or 20 % (**Figure 2**). Would the dominant form of moth wing become more and more common over time? Do allele frequencies remain constant or change over time?

These questions interested Reginald Punnett. Over a meal in 1908, Punnett posed them to Godfrey Hardy, an eminent mathematician, who, without hesitation, wrote a solution on a napkin. Working independently, German physician Wilhelm Weinberg formulated the same solution. Now referred to as the Hardy–Weinberg Principle, this mathematical relationship, outlined below, shows that allele frequencies will not change from generation to generation, as long as certain conditions are met.

Conditions of the Hardy–Weinberg Principle

Allele frequencies in a population will not change if

- the population is infinitely large
- no migration occurs
- no mutations occur
- no natural selection occurs
- mating is random

For a gene with only two alleles (*A* and *a*), the Hardy–Weinberg Principle can be expressed using the following equation:

If p = frequency of allele *A* and q = frequency of allele *a*, then

$$p + q = 1$$
$$(p + q)^2 = 1^2$$
and so $$p^2 + 2pq + q^2 = 1$$

p^2 = frequency of genotype *AA*
$2pq$ = frequency of genotype *Aa*
q^2 = frequency of genotype *aa*

DID YOU KNOW?

Hardy's Reluctance

When Punnett first saw Hardy's now famous equation, he suggested that Hardy publish the idea immediately. Hardy was reluctant, apparently not wanting his name associated with so simple an idea.

This equation gives the expected genotype frequencies of the population, when all the conditions of the Hardy–Weinberg Principle are met. We will refer to it as the Hardy–Weinberg equation. Note that after a single generation of random mating, the genotype frequencies are given by p^2, $2pq$, and q^2.

Applying the Hardy–Weinberg Principle

For the moth population in **Figure 2**, on the previous page, the allele frequency of the *A* allele is 0.80, or 80 %, and the frequency of the *a* allele is 0.20, or 20 %. If mating is random, when the population reproduces, 80 % of all gametes will bear the *A* allele, while the remaining 20 % of gametes will bear the *a* allele. The genetic recombination that occurs in the next generation is shown in **Figure 3**. Substituting these values into the Hardy–Weinberg equation, we get the following:

$$(0.80)^2 + 2(0.80)(0.20) + (0.20)^2 = 1$$
$$0.64 + 0.32 + 0.04 = 1$$

Therefore, the frequency of the *AA* genotype is 0.64, or 64 %, the frequency of the *Aa* genotype is 0.32, or 32 %, and the frequency of the *aa* genotype is 0.04, or 4 %. The genotype frequency values of offspring generations are the same as those for the parent generation. If random mating continues to occur, allele frequencies are likely to remain constant from generation to generation.

EXTENSION

Solving Problems Involving the Hardy–Weinberg Principle
Listen to this Audio Clip of some guiding principles for solving frequency calculations in problems dealing with the Hardy–Weinberg Principle.

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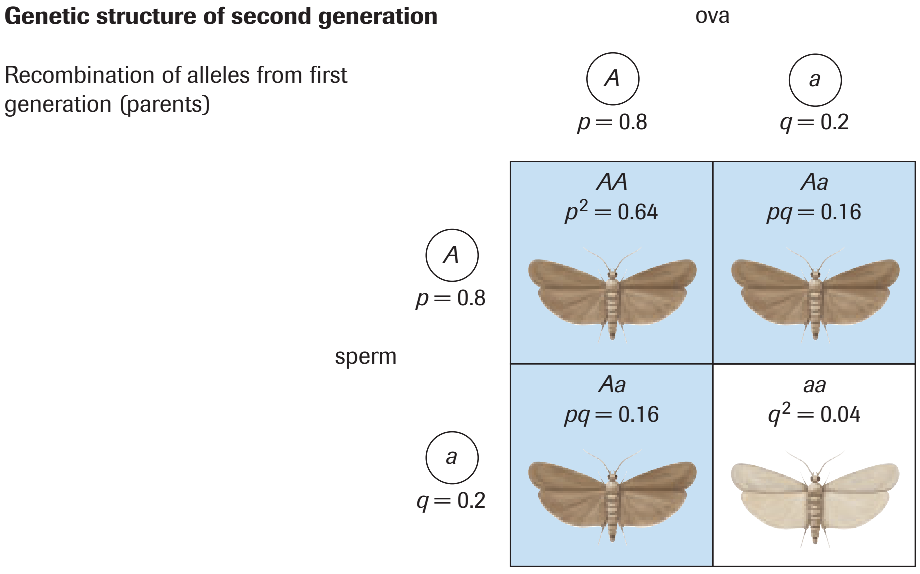

Second generation:

genotype frequencies	$p^2 = 0.64$ *AA*	$2pq = 0.32$ *Aa*	$q^2 = 0.04$ *aa*
allele frequencies	$p = 0.8$ *A*	$q = 0.2$ *a*	

Figure 3
A typical Punnett square shows a cross between two individuals. This one depicts the allele frequencies of offspring within the moth population in **Figure 2** on the previous page.

SAMPLE exercise 1

Apply the Hardy–Weinberg equation to solve the following problem, assuming that all five of the Hardy–Weinberg conditions are met:

A population has only two alleles, *R* and *r*, for a particular gene. The allele frequency of *R* is 20 %. What are the frequencies of *RR*, *Rr*, and *rr* in the population?

Solution

If *p* represents the frequency of allele *R*, *q* the frequency of allele *r*, and $p = 0.20$, then $q = 0.80$. Using the equation for the Hardy–Weinberg Principle, we get the following:

$$(0.20)^2 + 2(0.20)(0.80) + (0.80)^2 = 1$$
$$0.04 + 0.32 + 0.64 = 1$$

frequency of *RR* genotype = 0.04, or 4 %

frequency of *Rr* genotype = 0.32, or 32 %

frequency of *rr* genotype = 0.64, or 64 %

Practice

For all questions, assume that the conditions for the Hardy–Weinberg Principle are being met.

1. A large population consists of 400 individuals, of which 289 are homozygous dominant (*MM*), 102 are heterozygous (*Mm*), and 9 are homozygous recessive (*mm*). Determine the allele frequencies of *M* and *m*.
2. The gene pool of a certain large population of fruit flies contains only two eye-colour alleles: the dominant red allele, *R,* and the recessive white allele, *r.* Only 1 % of the population has red eyes. Determine the allele and genotype frequencies of this population.
3. Manx cats have no tails (or have very short tails) and have large hind legs. The no-tail trait results from a heterozygous genotype, *Tt.* Interestingly, *TT* genotypes are normal cats, while the *tt* genotype is lethal and cat embryos that possess it do not survive. In a population of 1000 cats, only 1 % are Manx and 99 % are normal.
   (a) What are the allele frequencies in this population?
   (b) Determine the expected frequency of each genotype in the next generation.
   (c) Determine the allele frequencies of the population of cats from (b).
   (d) What influence do homozygous recessive genotypes have on allele frequencies in this generation?
   (e) Predict the long-term result of a lethal homozygous recessive trait in a wild population.

Learning Tip

Turn to Appendix A7, Math Skills, for a review of how to correctly perform calculations using scientific notation.

WWW WEB Activity

Simulation—Hardy–Weinberg

In this activity, you will visit links on the Nelson Web site to observe various simulation models of populations. These simulations allow you to manipulate the conditions necessary for maintaining Hardy–Weinberg equilibrium. Your tasks are to

- experimentally test the effect of altering each condition
- critique at least two different simulation models and assess their strengths and weaknesses

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mini Investigation — Quantifying Human Genetic Variation

Humans possess several easily distinguishable traits, each of which is controlled by a single recessive and dominant allele combination.

- Select two of the following traits:
  - blue eyes
  - widow's peak
  - hitchhiker's thumb
  - attached earlobes
  - freckles
  - dimples
  - tongue rolling
  - long second toe (second toe extends beyond big toe)
- Research to determine if the trait is controlled by a dominant or a recessive allele.
- Survey at least 20 students in your class and record the presence or absence of the trait. If possible, share data with other classes to increase the sample size.
- Apply your understanding of genetics and the Hardy–Weinberg equation to estimate population allele frequencies.
- Conduct research to find the accepted allele frequency values.

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(a) How would your data have differed if you had surveyed your family members instead of students?

(b) Suggest methods you could use to determine if the alleles you studied were in Hardy–Weinberg equilibrium.

(c) Account for any differences between your findings and the accepted allele frequency values for the human population.

SUMMARY The Hardy–Weinberg Principle

- The gene pool of a population is determined by the alleles possessed by the individuals in the population. A gene pool can be quantified by measuring the allele frequency.
- According to the Hardy–Weinberg Principle, the gene pool of a population will not change when the following conditions are met:
  - The population is infinitely large.
  - No migration occurs.
  - No mutations occur.
  - No natural selection occurs.
  - Mating is random.
- When the Hardy–Weinberg conditions are met, then, for a gene with two alleles (A and a), the allele frequency in the population will be

  $$p + q = 1$$

  where p = frequency of allele A and q = frequency of allele a
- When all the Hardy–Weinberg conditions are met, then, for a gene with two alleles (A and a), the genotype frequency in the population will be

  $$p^2 + 2pq + q^2 = 1$$

  where p^2 = frequency of genotype AA, $2pq$ = frequency of genotype Aa, and q^2 = frequency of genotype aa

Section 21.1 Questions

1. Describe how the genetic diversity of a population is influenced by recombination and heterozygosity.
2. Study **Table 1** on page 716.
   (a) Suggest possible reasons that might account for the widely varying amounts of DNA found in these species.
   (b) *Necturus* and *Amphiuma* have similar sized genomes. Why is this not surprising?
   (c) The size of the genome does not provide any information on the genetic variability within chromosomes. How might polyploidy, non-coding sequences, and multiple alleles contribute to the genetic diversity of species?
3. Describe how gene duplication and recombination during meiosis contribute to the overall genetic diversity of populations.
4. Use the Punnett square in **Figure 4** to briefly explain how sexual reproduction increases the potential for genetic variation.

♂ parent *RrTt*

♀ parent *RrTt*

	RT	*Rt*	*rT*	*rt*
RT	*RRTT*	*RRTt*	*RrTT*	*RrTt*
Rt	*RRTt*	*RRtt*	*RrTt*	*Rrtt*
rT	*RrTT*	*RrTt*	*rrTT*	*rrTt*
rt	*RrTt*	*Rrtt*	*rrTt*	*rrtt*

Figure 4
A Punnett square showing the offspring of parents with identical genotypes and phenotypes. The possible phenotypes are represented in different-coloured cells.

5. For each of the following, predict whether Hardy–Weinberg equilibrium would be maintained generation after generation:
   (a) a population of African violets maintained by a plant breeder
   (b) the population of mosquitoes in northern Alberta
   (c) an elk population living in Banff
   (d) a newly discovered bird population on a remote island off the coast of British Columbia
6. A population of 200 includes 32 individuals that are homozygous recessive (*bb*) for a given trait. Assuming the population meets the conditions for Hardy–Weinberg equilibrium, how many of the 200 individuals would you expect to be homozygous dominant (*BB*)?
7. Cystic fibrosis is a recessive condition that affects about 1 in 2500 people in the Caucasian population of Canada. Calculate the following:
   (a) the population frequencies for the dominant (*C*) and recessive (*c*) alleles
   (b) the percentage of the population that is a carrier of the recessive allele
   (c) the number of students in your school that are likely to be carriers of the cystic fibrosis allele
8. A recessive allele (*h*) codes for complete hair loss in chimpanzees. Homozygous recessive individuals lose all their hair by about six months of age. Chimpanzees with one or two dominant alleles (*H*) show no signs of this disorder. In a population of captive chimpanzees, 16 % of the chimpanzees lose all their hair.
   (a) Calculate the allele frequencies of *H* and *h*.
   (b) What percentage of the chimpanzees could *not* be the parents of chimpanzees with this condition.
   (c) Hairless chimpanzees have reduced survival rates and lower reproductive success. Predict how the allele frequencies will change over time. Explain your reasoning as it relates to the Hardy–Weinberg equilibrium assumptions.

Changes in Gene Pools 21.2

The Hardy–Weinberg Principle predicts that, under a set of specific conditions, a gene pool will remain unchanged from generation to generation. The underlying conditions are critically important. When the conditions of the Hardy–Weinberg Principle are not met, a gene pool is predicted to change in the following ways:

- When a population is small, chance fluctuations will cause changes in allele frequencies.
- When individuals migrate, they will remove alleles from one population and add them to another.
- When mutations occur, new alleles will arise or one allele will be changed into another, thereby changing the allele frequencies in the population.
- When natural selection occurs, individuals with certain alleles will have greater reproductive success than others do, thereby increasing the relative frequency of their alleles in the next generation.
- When mating is not random, individuals that are preferred as mates will pass on their alleles in greater numbers than less preferred mates.

Real populations can be affected by any of these conditions, resulting in changes to allele frequencies in the gene pool.

Genetic Drift

Genetic drift is a change in the genetic makeup of a population resulting from chance. When populations are small, chance can significantly alter allele frequencies. For example, assume that only 1 in 100 whooping cranes carries a particular allele, C_1 (**Figure 1**). If the whooping crane population had 10 000 individuals, you would expect 100 birds to carry the allele. If half the population died in a severe storm, for example, about 50 of the 5000 survivors would have the C_1 allele. Therefore, the allele frequency is not expected to change significantly. If the whooping crane population is only 200 individuals, only two birds would have the C_1 allele. If half of this population died, both the C_1 carriers could die, eliminating the C_1 allele entirely. If both survived, then the C_1 allele frequency would double.

genetic drift changes to allele frequency as a result of chance

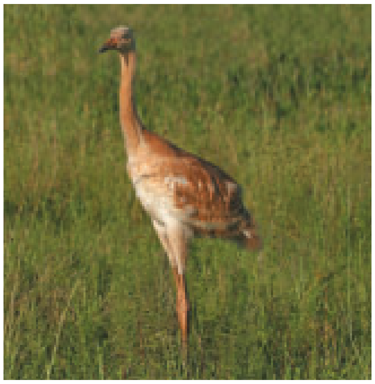

Figure 1
A young whooping crane. In 1941, there were only 22 individuals left in Alberta. Today, the breeding population in Wood Buffalo National Park remains very susceptible to the effects of genetic drift.

Figure 2, on the next page, shows how population size affects genetic drift. **Figure 2 (a)** illustrates genetic drift in a population of 25 stoneflies. The frequency of allele *A* fluctuates wildly from generation to generation. In five of the trials, the *A* allele frequency became fixed at 100 % in 22 generations or fewer. In the other four trials, the *A* allele was lost entirely in 36 generations or fewer. In a larger population of 500 stoneflies, shown in **Figure 2 (b)**, the allele frequency remained relatively stable even after 50 generations had passed. There was no trend toward fixing of the allele. In small populations, genetic drift can lead to fixation of alleles. This increases the percentage of homozygous individuals within a population and reduces its genetic diversity.

When a few individuals from a large population leave to establish a new population, the resulting genetic drift is called a **founder effect**. The allele frequencies of the new population will likely not be the same as those of the original population and may deviate further as the new population expands. Founder effects seem to be common in nature, such as when a few seeds carried by a bird or by winds to a distant volcanic island may germinate and rapidly establish a large population. With self-pollinating plants, an entire population can be established from a single fertile seed. Founder effects can also be seen in

founder effect genetic drift that results when a small number of individuals separate from their original population and find a new population

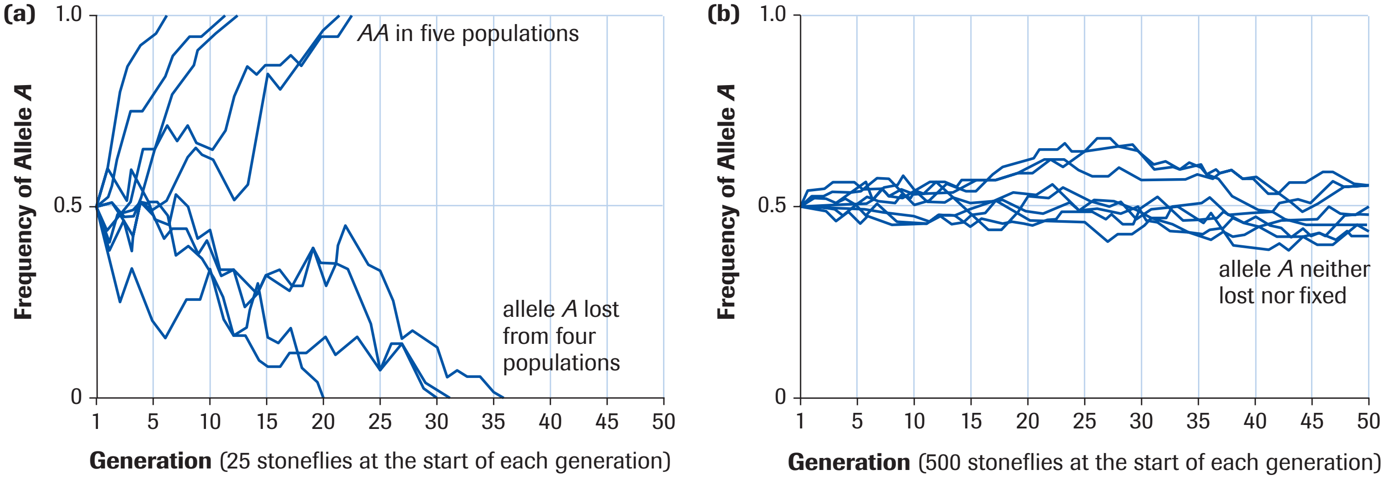

Figure 2
(a) In small populations, genetic drift can result in dramatic changes in allele frequencies.
(b) In larger populations, genetic drift is not usually significant.

human populations. Members of the Amish community in Pennsylvania are all descendants of about 30 people who emigrated from Switzerland in 1720. One of the founders had a rare recessive allele that causes unusually short limbs. The frequency of this allele in the current Amish population is about 7 %, compared to a frequency of 0.1 % in most populations.

bottleneck effect a dramatic, often temporary, reduction in population size, usually resulting in significant genetic drift

When a severe environmental event results in a drastic reduction in population size, a population may experience a **bottleneck effect** (**Figure 3**). With the bottleneck effect, the frequency of alleles in the survivors is very different from that in the original population. Additional genetic drift may result in further changes in the gene pool. This is known to have occurred with the northern elephant seal (**Figure 4**).

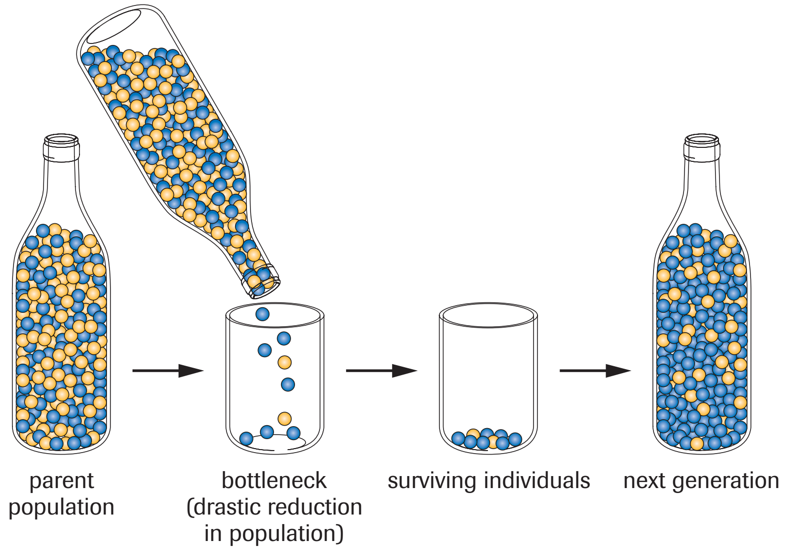

Figure 3
A dramatic, sometimes temporary, reduction in the size of a population can result in a bottleneck effect.

Figure 4
The northern elephant seal population was reduced by overhunting to 20 individuals in the 1890s. Although the population had rebounded to over 30 000 individuals by 1974, 24 gene loci were found to be homozygous by genetic testing.

mini Investigation: Demonstrating Chance

See for yourself how random chance works in small populations.

A large population of birds possesses six different alleles for a specific gene. All alleles are present in equal frequencies. Assume that 30 individuals are randomly separated from the original population and become established on a remote island. Let the alleles be represented by the numbers 1 to 6.

- Model the initial allele frequency of the new population by tossing a six-sided die 30 times. Record your results.
- Examine the results obtained by your classmates.

(a) How often did you roll a three? Did your response differ from the one-sixth you would expect by chance?

(b) How many times did you roll a three in your first six tosses? What ratio did this produce?

(c) Relate the variations in the frequencies of the number three to variations in allele frequencies that occur when small founder populations form.

Gene Flow

When organisms migrate, leaving one population and joining another, they alter the allele frequencies of both populations. Such **gene flow** occurs frequently in most wild populations. For example, prairie dogs live in dense colonies consisting of a few dozen members. For much of the year they prevent other prairie dogs from joining their colony. In late summer, however, mature male pups are permitted to enter new colonies, thereby affecting both gene pools. New alleles may be added or rare alleles lost during such events. Gene flow can also occur when individuals of adjacent populations mate without moving permanently. In these ways, genetic information is shared between populations. Unlike genetic drift, gene flow tends to reduce differences between populations.

gene flow the movement of alleles from one population to another through the movement of individuals or gametes

Mutations

As you have previously learned, mutations are randomly occurring events that alter the inheritable genetic material of an individual. Mutations are the source of new genetic diversity in a species as a whole. Mutations vary considerably in size. They range from the alteration of a single base pair in a DNA molecule to large-scale changes such as multi-base-pair deletions, insertions, or inversions.

Many mutations are neutral mutations, and have no effect on the individual or its reproductive success. Other mutations may be beneficial mutations (enhancing reproductive success) or harmful mutations (reducing reproductive success). You will find more information about mutations in Chapters 5 and 20. When a mutation arises in a population, it has the potential to alter the gene pool or allele frequencies of the population, and therefore the Hardy–Weinberg equilibrium. However, the mutation will not influence the entire population or species unless the resulting genetic change becomes relatively common. Genetic changes resulting from mutations become common when they are beneficial to the individuals that possess them. As you have learned, inheritable characteristics that are favoured by natural selection become more common over time. Since these traits are determined by specific alleles then, as a result of natural selection, the allele frequencies (or genetic makeup) of a population will change over time. Most natural populations are large and reproduce rapidly, with each new individual inheriting a very large number of alleles. Although the chances of a mutation arising in any specific allele are low, new mutations arise often and continuously in the population as a whole.

DID YOU KNOW?

Lots of Mutations

It has been estimated that each new human cell contains about 100 new mutations. Although this number seems high, most of the mutations occur in non-coding DNA sequences.

EXPLORE an issue

Issue Checklist

- ○ Issue
- ● Resolution
- ○ Design
- ● Evidence
- ● Analysis
- ● Evaluation

Genetic Diversity at Risk

In this activity, you will examine several significant threats to genetic diversity that face both wild and domesticated species, and learn how biologists and conservationists are addressing these threats. What do you already know about the Threats listed in **Table 1**? Are you familiar with any of the Actions that are being taken to preserve genetic diversity?

- Share your prior knowledge about these topics with members of your group.
- Choose one Threat and a related Action with your group. For example, you might choose the loss of crop-seed varieties (Threat) and the establishment of seed banks (Action).
- Conduct some preliminary research to determine the general nature of the Threat and the Action. During your research, document the global status of the Threat and the scope of the Action. Consider the factors that are driving the Action. What are the underlying causes of this Threat and what are the motivating concerns behind the Action? Consider both the short-term and long-term implications of the Threat and the Action. What is predicted to happen if the current Threat persists or if the Action is unsuccessful?

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- When research is completed, select examples you think best exemplify the Threat and Action you reviewed. Conduct more in-depth research on these examples and document your findings.

(a) Prepare a class presentation on your Threat and Action. Make sure that your presentation
  - provides an overview of the Threat and the Action
  - accounts for the root cause of the Threat
  - highlights examples in detail
  - relates the topic directly to the impact of human activities
  - includes a summary flowchart that relates the Threat to the Action

Table 1 Some Threats to Genetic Diversity and Actions to Reduce Its Effect

Threats to genetic diversity	Actions to protect genetic diversity
• habitat loss such as clearing of tropical rainforests, elimination of wild-grass prairies, and coral-reef bleaching • over-harvesting of individual species • fragmentation of wilderness, leading to small isolated populations • competition with exotic species • loss of traditional domesticated animal and plant crop varieties	• establishment of natural reserves and parks • international treaties to protect species and ecosystems • direct protection of endangered species and their primary habitat • creation of gene and seed "banks" • captive animal- and plant-breeding programs in zoos and botanical gardens

Natural Selection

Mutations provide a continuous supply of new genetic variations, which may be inherited and expressed as different phenotypes. Natural selection then acts on these mutations. Although mutations provide the source of variation, natural selection acts on individuals and their phenotypes. As a result, particular alleles are most successful and passed on when they enhance the phenotype of the individual and, thereby, contribute to their reproductive success. Selective forces can favour particular variations in the phenotype of individuals in a number of ways. Sickle-cell anemia, a potentially serious blood disorder, is a useful example of how mutation, genetic variation, and the environment result in different patterns of natural selection.

The allele for sickle-cell anemia differs from the normal hemoglobin gene by a single base-pair mutation. Individuals homozygous for the sickle-cell allele are severely afflicted with this disorder. Heterozygous individuals are only mildly affected by sickle-cell anemia; however, they are much more resistant to malaria than are people with normal hemoglobin. In regions where malaria is uncommon, individuals with the sickle-cell allele are at a disadvantage and their phenotypes are less likely to contribute alleles to the gene pool. But in regions where malaria is common (**Figure 5**), heterozygous individuals are strongly favoured; they are much more likely to survive and pass on their genes to the next generation. The environment selects the best-adapted phenotype and, in so doing, favours a particular set of alleles.

DID YOU KNOW?

Selection of Another Hemoglobin Allele?

In November 2001, geneticists reported in the journal *Nature* about another mutated form of the hemoglobin gene that provides resistance to malaria. Unlike the sickle-cell allele (*HbS*), individuals with two copies of the *HbC* allele show no signs of disease and are very resistant to even the most serious form of malaria. Interestingly, the mutation in the β-hemoglobin gene that produced the *HbC* allele is in the identical location as the *HbS* allele.

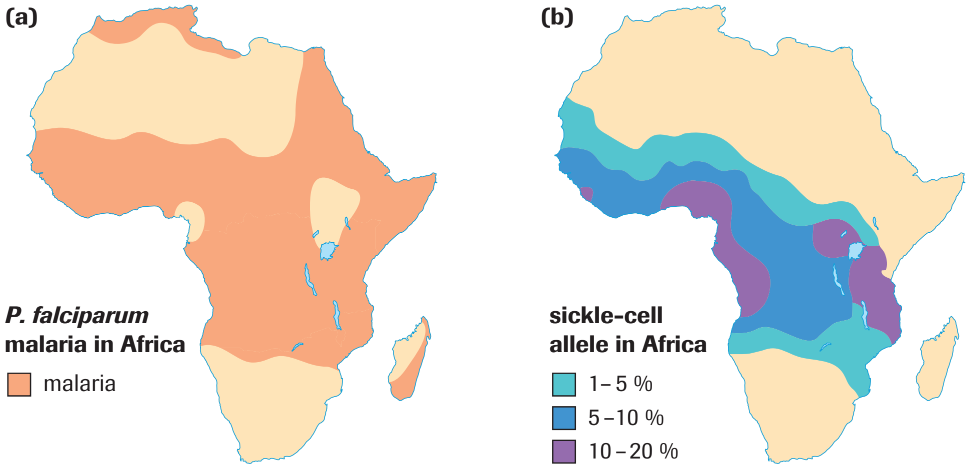

Figure 5
Of the 120 million new cases of malaria each year, about 1 million are fatal. The prevalence of malaria in Africa in **(a)** closely matches the distribution of the sickle-cell allele in **(b)**. The percentages are estimates of a distribution range.

The sickle-cell allele is only common where it provides an overall advantage to the individual. In populations where it has an overall harmful effect, it does not persist. This pattern demonstrates an important relationship between mutations and gene pool changes in a population:

- Harmful mutations occur frequently, but they are selected against and, therefore, these mutant alleles remain extremely rare.
- Beneficial mutations are rare, but they are selected for and, therefore, these mutant alleles may accumulate over time.

CAREER CONNECTION

Anthropologist
Anthropologists study changes in human physical characteristics and relate them to influences of heredity and environment. There are many different branches of anthropology, and the range of research interest is very broad. Are you interested in studying how human populations have changed over time?

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Case Study

Antibiotic-Resistant Bacteria

An article in the *Canadian Medical Association Journal* (July 2001) reported an alarming six-fold increase in the rate of antibiotic resistance in Canada between 1995 and 1999. In addition to added health risks, fighting antibiotic resistance can be expensive. Across Canada, the cost is estimated at $50 to $60 million a year.

In 1996, doctors took samples of bacteria from a patient suffering from tuberculosis, a lung infection caused by the bacterium *Mycobacterium tuberculosis.* Cultures of the bacteria found it to be sensitive to a variety of antibiotics, including rifampin. The patient was treated with rifampin and initially responded so well that the lung infection seemed to be over. Soon after, however, the patient had a relapse and died. An autopsy revealed that bacteria had invaded the lungs again in large numbers. Cultures of these bacteria were found to be sensitive to many antibiotics, but resistant to rifampin. DNA sequencing revealed that a certain bacteria's gene had a single base-pair mutation that was known to confer resistance to rifampin. Doctors compared the new bacteria culture with the original culture and found that the sequences were identical except for this single mutation. Researchers then examined more than 100 strains of bacteria from other tuberculosis patients living in the same city at the same time. None of these bacteria had the same genetic code as the rifampin-resistant bacteria obtained in the autopsy. When doctors had begun administering rifampin, the bacteria in the patient had been subjected to a new environmental selective agent, one that gave the mutant strain a major adaptive advantage.

The pattern in this story is not uncommon, but evolution offers some hope as well as alarm. Many traits that provide antibiotic resistance are harmful to the bacteria. For example, a strain of *E. coli* bacteria possesses a plasmid with a gene that enables it to produce an enzyme called b-lactamase. This enzyme gives the bacterium resistance to the antibiotic ampicillin. However, there is a cost for this resistance: to maintain its antibiotic resistance, the bacterium must devote cellular resources to producing the enzyme and to making copies of the plasmid before cell division, slowing its growth rate. In another example, the bacterium *Mycobacterium tuberculosis* normally produces catalase, a beneficial but non-essential enzyme. This enzyme, however, activates the antibiotic isoniazid, which destroys the bacterium. Bacteria that have a defective catalase gene are, therefore, resistant to isoniazid—as it cannot be activated in the absence of catalase—but they lack the benefits normally provided by the enzyme. As a result of these costs of resistance, when an antibiotic is not present, natural selection often favours those bacteria that do not carry antibiotic-resistant alleles.

Case Study Questions

1. Did the rifampin-resistant bacteria found in the autopsy evolve within the patient's lungs or did they result from a brand new infection? Explain the evidence.
2. Most antibiotics are derived from microorganisms that do not occur naturally in the human body. Most infectious bacteria showed no resistance to these antibiotics when they were first used in the 1940s. Why?
3. Bacteria that are not resistant to antibiotics usually out-compete resistant strains in the absence of antibiotics. Account for this observation.
4. Tuberculosis patients are now routinely given two different antibiotics at the same time. Why might this approach be more effective than administering a different antibiotic only after bacteria develop resistance to the first?
5. Suggest some strategies that could help reduce the incidence of antibiotic resistance in your own home, your school, and in society at large.

Non-Random Mating

Individuals that mate and reproduce frequently make a substantial contribution to the gene pool of later generations. **Sexual selection** favours the selection of any trait that influences the mating success of the individual. The traits favoured in sexual selection include **sexual dimorphism** (i.e., striking differences in the physical appearance of males and females) and behavioural differences between the sexes. The most common forms of sexual selection result from female mate choice and from male-versus-male competition. In some species, females choose mates based on physical traits, such as bright coloration, or behavioural traits, such as courtship displays and song. In other species, males are equipped with physical features that assist them in establishing control of and defending their territory against other males (**Figure 6**). This territory provides an area to which they can attract, and sometimes forcibly detain, the females with which they mate. Such traits are not produced by selective pressures from environmental conditions; if they were, both sexes would be expected to possess them.

Many species have evolved features that are a compromise between different selective pressures. Sexual selection has produced traits that are beneficial for mating, but may otherwise be detrimental. Avoiding predators is not made easier, for instance, by brilliant plumage or a distinctive song.

sexual selection differential reproductive success that results from variation in the ability to obtain mates; results in sexual dimorphism and mating and courtship behaviours

sexual dimorphism striking differences in the physical appearance of males and females not usually applied to behavioural differences between sexes

EXTENSION

The Hardy-Weinberg Principle "Agents of Change"

This Audio Clip summarizes the "agents of change" predicted by the Hardy-Weinberg Principle and explains how each can change allele frequency and genotype frequency of a population.

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Figure 6
Sexual dimorphism may take the form of a physical feature. For example, female fiddler crabs lack the special enlarged right claw of the male as seen here.

Sexual diversity is not limited to animal populations. Most plants do not select mates, but they do need to attract or use various agents—such as insects, birds, and bats—to assist in pollination. Flowers and scents are the most obvious sexual features that have evolved through natural selection.

Not all species show obvious sexual dimorphism. In some species of penguin, males and females look so similar that even they have a hard time telling each other apart (**Figure 7**). A male picks up a stone and drops it at the feet of a would-be mate. If the other penguin happens to be a male, the gift is firmly rejected.

Figure 7
Penguin species that lack sexual dimorphism instead have behaviours that allow them to distinguish males from females.

WEB *Activity*

Web Quest—Hardy–Weinberg and the Colour of Guppies

The use of computer models is very important in a lot of current scientific research. Many multi-disciplinary teams work together on common projects, and the use of models often allows these teams to share findings. In this Web Quest, you and the members of your class will form a research team exploring variation in coloration of a population of guppies. In groups, you will explore several computer models of the Hardy–Weinberg principle. Each group will then use one of these models to explain the colour variations, and then present the results to the rest of the research group. The entire multi-disciplinary research team will then reach a consensus explanation.

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INVESTIGATION 21.1 ***Introduction***

Agents of Change

Population size, genetic drift, and natural selection all affect allele frequencies. Using coloured beads to model alleles in a population, you will design and conduct an investigation to explore how population size, genetic drift, and natural selection effect changes in allele frequency. How can the influence of these factors be predicted?

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	● Procedure	● Synthesis
○ Prediction	● Evidence	

To perform this investigation, turn to page 731.

SUMMARY *Changes in Gene Pools*

- When Hardy–Weinberg conditions are not met, the gene pool of a population may change over time.
- In small populations, genetic drift (including the bottleneck and founder effects) and gene flow may change allele frequencies and genetic diversity.
- Migration may cause gene flow, in which alleles are removed from the gene pool of one population and added to another.
- Mutation may change the frequency of existing alleles and add new alleles to the gene pool.
- Natural selection may change allele frequencies in a gene pool by selecting against harmful alleles and selecting for beneficial alleles
- Non-random mating may cause some alleles to occur more or less frequently in the gene pool of the next generation.

Section 21.2 Questions

1. Define genetic drift and genetic flow, offering two examples to illustrate each definition.
2. Suggest three types of organisms that might produce founder populations. Explain the process that results in this effect.
3. The world's population of cheetahs is almost identical genetically. Male cheetahs are known to have low sperm counts and the species in general has a low resistance to many infectious diseases. All cheetahs are thought to be homozygous at over 99.9 % of their gene loci. Explain how a severe genetic bottleneck effect in the past could account for these observations.
4. If variation in species were solely a result of genetic recombination during sexual reproduction, how would that limit the evolution of species?
5. Relate two ways in which alleles can become fixed in a population.
6. It is thought that a billion prairie dogs once populated an area of more than 100 million ha. Their current territory has been reduced and fragmented to less than 1 % of this original space. Predict the impact of these changes in habitat on the prairie dog gene pool, as well as on the survival of the species.
7. The present population of whooping cranes suffers from low genetic diversity and susceptibility to a variety of diseases. Which of the founder effect, the bottleneck effect, and gene flow are likely to account for these observations?
8. Many insect species have evolved resistance very rapidly to a range of pesticides. Like other species, insects exhibit variation in physical, chemical, and behavioural traits.
   (a) Describe how an insect species would evolve resistance to a pesticide newly introduced into its environment.
   (b) How might high rates of reproduction and the short duration of insect generations affect their evolution?
   (c) How might an understanding of the evolution of pesticide resistance influence how you use pesticides or alternative methods of insect control?
9. In recent years, many Africans who are carriers of the allele for sickle-cell anemia have emigrated from malaria-stricken areas in Africa to North America. Has this influenced the biological role of the sickle-cell allele? Explain.
10. Suggest how large antlers or bright coloration could be a disadvantage for males of some species.
11. Although, in theory, an individual could mate at random with other members of a large population, this seldom occurs. Under most natural conditions, individuals tend to mate with nearby members of the same species, especially if they are not very mobile. Alternatively, individuals choose mates that share similar traits; for example, toads (and often humans) tend to pair according to size.
    (a) How might inbreeding (the mating of closely related individuals) lead to an increase in the number of sometimes harmful recessive phenotypes? Relate your answer to either a population of cheetahs in the wild or a population of golden retrievers in a breeding kennel.
    (b) Does nonrandom mating result in changes to population phenotype frequencies, genotype frequencies, or allele frequencies?
12. In many zoos, artificial insemination of female tigers is becoming common practice. Semen is collected from male tigers in various zoos around the world, frozen in liquid nitrogen, and shipped to zoos where it is used to inseminate female tigers in estrus.
    (a) Why do you think this is being done?
    (b) How might this affect the gene pool of tiger populations?
    (c) Do you think these efforts are enough to prevent a genetic bottleneck from occurring? Explain.
    (d) What conditions do you think are necessary to ensure the genetic diversity of zoo populations?
13. Insect resistance to pesticides is estimated to cost tens of millions of dollars per year in Canada. The Colorado potato beetle, for example, developed resistance to five different pesticides over a period of only 15 years. Predict how such evolutionary consequences might affect and concern consumers, ecologists, pesticide companies, organic farmers, and plant breeders.

INVESTIGATION 21.1

Agents of Change

In this investigation, you will design and conduct experiments to examine the influence of population size, genetic drift, and natural selection on the rate of evolution, by measuring changes in allele frequencies.

Work with your partner to develop a design and conduct experiments for Parts 1, 2, and 3, using or modifying the procedure below. Prepare data collection tables. Submit your modified experimental design to your teacher for approval before conducting each of your three experiments.

Report Checklist

○ Purpose	● Design	● Analysis
● Problem	○ Materials	● Evaluation
● Hypothesis	● Procedure	● Synthesis
○ Prediction	● Evidence	

Problem

How do genetic drift and natural selection influence the allele frequency within a population?

Materials

80 or more beads in colour A (to represent allele *R*)
80 or more beads in colour B (to represent allele *r*)
large opaque container (to represent a gene pool)

Immediately pick up any beads that drop on the floor, as they might cause someone to slip.

Procedure

1. Place 40 beads of each colour (80 beads in total) in the large opaque container.
2. Thoroughly mix the "alleles" (beads) in the "gene pool" (container).
3. At random, reach into the gene pool and take out 20 pairs of alleles to represent offspring genotypes that contribute to the next generation.
4. Determine and record the number of each genotype (e.g., 5 *RR*, 7 *Rr*, 8 *rr*).
5. Record the F_1 allele frequencies as decimal values. For example, divide 17 *R* and 23 *r* by 40 to get the frequencies of 0.425 *R* and 0.575 *r*, respectively.
6. Place the next generation of 80 beads in the "gene pool" container in the same proportions of allele frequencies as the "offspring" (e.g., $0.425 \times 80 = 34$ *R*, $0.575 \times 80 = 46$ *r*).
7. Repeat steps 3 to 6 for four additional generations.

Part 1: Random Mating, No Selection

8. Run at least two trials in which you use large populations and meet the conditions of the Hardy–Weinberg Principle. These trials act as your control in Part 2 and Part 3.

Part 2: Genetic Drift

9. Run at least two trials in which you examine the influence of population size on the degree and rate of genetic drift. Choose two or more starting populations of different sizes. As an option, you may also wish to model a founder effect.

Part 3: Natural Selection

10. Run at least two trials in which natural selection occurs. You might model a favoured homozygous genotype in which, for example, *RR* offspring might be twice as successful as other genotypes. If so, you would need to allow for the increased ratio of offspring contributing to the next generation, while maintaining a stable, large population. As an option, you could investigate selection against a homozygous lethal allele by assuming that each time a specific homozygous allele pair is selected, it dies, and you have to keep adding pairs until you have 20 offspring. Another option is to investigate a selective advantage for a dominant phenotype.

Analysis and Evaluation

(a) Make a separate graph of the data you collected for each of Parts 1, 2, and 3, by plotting allele frequency versus generation. On each graph, use two different colours on the same set of axes to represent the *R* and *r* alleles.

(b) How did population size influence the degree and rate of evolutionary change? Did any alleles become fixed in a population? In what size populations might you expect it to be relatively common for alleles to become fixed? Why?

(c) What conditions occur in nature that result in small populations?

(d) How did natural selection influence the degree and rate of evolutionary change? Did any alleles become fixed in the population?

(e) Were your results unusual compared with similar conditions in other groups?

(f) For each of your experiments in which evolution did occur, which of the five conditions of the Hardy–Weinberg Principle was not met?

Synthesis

(g) Assume you introduced a single new mutant allele to your population. Explain what you expect would happen under each of the following conditions:

- (i) The mutant is harmful and the population size is large.
- (ii) The mutant is harmful and the population size is small.
- (iii) The mutant is beneficial and the population size is large.
- (iv) The mutant is beneficial and the population size is small.
- (v) A beneficial mutant is introduced and the population is observed four generations later.
- (vi) A beneficial mutant is introduced and the population is observed 400 generations later.

Chapter 21 SUMMARY

Outcomes

Knowledge

- describe the Hardy–Weinberg Principle and explain its importance to population gene-pool stability and the significance of non-equilibrium values (21.1)
- describe the factors that cause the gene pool diversity to change, i.e., genetic drift, gene flow, non-random mating, bottleneck effect, migration, mutation, natural selection, and founder effect (21.2)
- apply quantitatively the Hardy–Weinberg Principle to observed and published data to determine allele and genotype frequencies (21.1)
- describe the molecular basis of gene-pool change and the significance of these changes over time, i.e., mutations and natural selection (21.2)

STS

- explain that science and technology have both intended and unintended consequences for humans and the environment (21.2)
- explain how concepts, models, and theories are often used in interpreting and explaining phenomena (21.1)

Skills

- ask questions and plan investigations (21.2)
- conduct investigations and gather and record data and information by: designing and performing an investigation to demonstrate population growth and gene-pool change (21.2)
- analyze data and apply mathematical and conceptual models by: calculating and interpreting problem-solving exercises involving the Hardy–Weinberg Principle (21.2)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

21.1

allele frequency
fixed frequency

21.2

genetic drift
gene flow
founder effect
sexual selection
bottleneck effect
sexual dimorphism

Key Equation

Hardy–Weinberg Equation

If p = frequency of allele A and q = frequency of allele a, then

$$p + q = 1$$
$$(p + q)^2 = 1^2$$
$$p^2 + 2pq + q^2 = 1$$

where p^2 = frequency of genotype AA, $2pq$ = frequency of genotype Aa, and q^2 = frequency of genotype aa

MAKE a summary

1. Evolution in its simplest form is the change in the gene pool of a species over time. According to the Hardy–Weinberg Principle, gene pool changes do not occur in populations if certain conditions are met. Write a detailed article to address this apparent contradiction. Explain how each of the following may cause gene pool change:
   - random chance
   - gene flow
   - small population size
   - natural selection
   - mutation
   - sexual selection
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 21
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

CBC radio ONE QUIRKS & QUARKS

Fowl Play: Disappearing Diversity

Dr. Mary Delany (assistant professor at the University of California, Davis), Dr. Donald Shaver (former head of the Shaver group, one of Canada's largest poultry breeders), Dr. Frank Robinson (professor of poultry management and physiology at the University of Alberta), and Dr. David Notter (Virginia Tech) discuss their various viewpoints on the genetic issues of Canada's commercial poultry. The gene pool for these birds is very small, and outside stock to maintain the gene pool is disappearing.

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Chapter 21 REVIEW

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Identify which of the following conditions is not necessary to maintain Hardy-Weinberg equilibrium in a population.
A. Mating must be random.
B. The population must be large.
C. Initial allele frequencies must be equal.
D. Immigration or emigration cannot occur.

2. A small number of individuals establish a new population with a distinct set of allele frequencies that is isolated from the parent population. This is referred to as
A. evolution
B. a bottleneck
C. genetic drift
D. the founder effect

3. When a population does not meet the conditions necessary for maintaining Hardy–Weinberg equilibrium, it will
A. evolve
B. increase rapidly in population size
C. result in all allele frequencies becoming equal
D. usually decline in numbers, leading to extinction

4. Four percent of an African population is born with a severe form of sickle-cell anemia (*ss*). The percentage of the population that will be heterozygous (*Ss*) for the sickle-cell gene is
A. 4 %
B. 16 %
C. 32 %
D. 96 %

5. The bottleneck effect is *not* associated with
A. increases in mutation rate
B. small populations
C. increases in the risk of extinction
D. enhancement of the influence of genetic drift

6. Which of the following traits is probably *not* associated with sexual selection?
A. defending a nesting territory
B. extreme running speed in pronghorn antelope
C. the large, bright tail feathers of a male peacock
D. differences in size between male and female wood buffalo adults

7. Antibiotic resistance is largely a result of
A. genetic drift
B. many random mutations
C. an evolutionary response to a change in the environment
D. the same individual bacterium being repeatedly exposed to antibiotics

8. A gene for which there exists only a single allele in the population are referred to as
A. fixed
B. recessive
C. dominant
D. homozygous

9. NR For each of the factors given below, determine the number that would be expected to increase the rate of genetic change over time. (Record all four digits of your answer in lowest-to-highest numerical order.)
1. large population
2. random breeding
3. migration
4. stable environment
5. non-random breeding
6. changing environment
7. small population
8. no migration

Part 2

10. Outline in a list the conditions that must be met to satisfy the Hardy–Weinberg equilibrium in a population. Clearly **explain** how the failure to meet any one of the conditions can lead to evolutionary change.

11. If beneficial mutations are much more rare than harmful ones, **how** can they have such an important role in evolution?

12. Illustrate, with an example, how random chance can have a greater effect on small populations than on larger populations.

13. Sketch **Figure 1** into your notebook, adding relevant labels. **Identify** and **describe** the effect that your sketch illustrates.

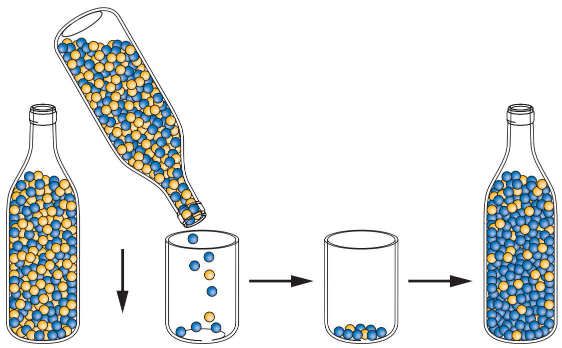


Figure 1

14. **Outline** in a list and **explain** some of the factors that have led to the rapid evolution of antibiotic resistance among many bacteria.

15. Would you expect bacteria occurring in wildlife, or in domesticated animals, to show signs of antibiotic resistance? **Explain** your answer.

16. DE A small population of pygmy mammoths measuring only 2 m in height once lived on a small island off the coast of California. Biologists believe this is an example of a population that descended from a few large mammoths that reached the island more than 50 000 years ago. In a unified response, **explain** how the following factors might have contributed to the formation of this unusual species:
- the small founding population,
- the remote location, and
- natural selection on this island.

17. Before the large-scale movement of people around the world, including the slave trade, the sickle-cell allele was extremely rare except in regions where malaria occurs. Based on this distribution, is it accurate to describe the allele as harmful? **Explain**.

18. In a population of 40 000 bats, you have identified two distinct phenotypes that result from two alleles at a single gene locus. One allele (*C*) produces dark brown hair and the other (*c*) produces cinnamon-coloured hair. If only 16 bats are cinnamon-coloured, **determine** the allele frequencies in the population. Assume the population is in Hardy–Weinberg equilibrium.

19. Suppose that 1 in 400 people in a large population have a recessive disorder. Apply the Hardy–Weinberg Principle to **determine** the proportion of individuals who are carriers of (i.e., heterozygous for) this disorder.

20. **Predict** how the genetic diversity of a population of lake trout from a small lake in northern Alberta would compare with the genetic diversity of a population of lake trout in Lake Winnipeg. **How** might you investigate your prediction?

21. In order to mate, sage grouse males gather in "leks" and engage in unusual display behaviours in hopes of attracting females. **How** would this behaviour influence the Hardy–Weinberg equilibrium in such a population?

Use the following information to answer questions 22 to 24.

An unusual group of black bears live in the rainforests of British Columbia. The Kermode (spirit) bears are white, a trait coded for by a recessive allele (*k*). The more common black colour is coded for by a dominant allele (*K*). On Princess Royal Island, approximately 10 % of the bears are white in colour.

22. DE **Determine** the frequencies of both the recessive and dominant alleles in the population.

23. DE **Determine** the percentage of the population you would expect to be carriers of the *K* allele.

24. DE Assume that the bear population behaves according to the Hardy–Weinberg equation. **Predict** what would happen to the frequencies of *K* and *k*, if the entire population doubled in size.

Use the following informationto answer questions 25 to 27.

The wood buffalo population in Elk Island National Park began with the introduction of a small founder population of 11 animals whose parents lived in Wood Buffalo National Park. Recent DNA studies indicate that the genetic diversity of the Elk Island population is much lower than that of the Wood Buffalo National Park population.

25. DE **Explain** the lower genetic diversity in the Elk Island population.

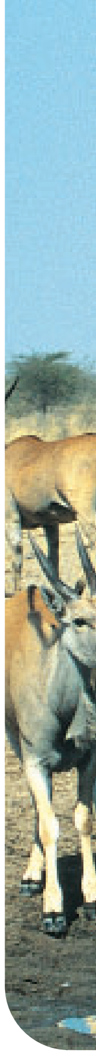
26. DE **Identify** the population that would be most able to respond to environmental changes? **Justify** your choice.

27. DE A wildlife officer wants to establish a population of wood buffalo elsewhere, using animals from the Elk Island captive population. **Describe** what precautions might the officer take to increase the chances of success?

28. The majority of the Afrikaner population in South Africa is descended from a single shipload of Dutch immigrants in 1652. Compared to the Dutch population, these descendants have a much higher incidence of such rare genes as the ones that cause Huntington's disease and the enzyme defect *variegate porphyria*. **Describe** the most likely explanation for these observations.

chapter

22 Population Changes



In this chapter

- Exploration: Moving Populations
- Web Activity: Dr. Stephen Herrero
- Web Activity: Wildlife Tracking
- Mini Investigation: Blogs in a Bottle: Population Growth in a Finite Environment
- Investigation 22.1: Measuring Population Changes
- Explore an Issue: Carrying Capacity Changes in a Warm Arctic
- Career Connections: Ecologist; College, Technical, or Vocational Instructor

Populations of organisms are dynamic (**Figure 1**). Some populations, such as those of the African black rhinoceros and the Vancouver Island marmot, are in serious decline and threatened with imminent extinction unless drastic action is taken. Other populations, such as those of the California sea lion along the west coast of North America and the cane toads in Australia, are experiencing unprecedented growth. While the number of chimpanzees, our closest living relative, has declined from about 2 million in 1900 to less than 150 000 at present, our own population has increased by more than 4 billion in the same time frame.

Can the extinction of entire species be avoided? What are the consequences of rapid population growth? To answer these questions, biologists must study populations carefully and observe and monitor changing environmental conditions. Changes in population numbers and in the patterns of distribution of individuals can have direct effects on the local ecosystem and may affect the well-being of other species within the ecological community.

Population ecologists use specialized methods to monitor, quantify, and model changes in populations. They also study the interrelationships between different species. In this way, they gather data necessary to predict future trends in the growth of populations. This information can be used to assess the health of individual species and entire ecosystems, to develop policies and plans of action to save species from extinction, and to address the impacts of rapidly growing populations.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

Study **Figure 1** on the next page and reflect on the following:

1. What relationships might exist among these animals?
2. List and explain factors in this environment that might be responsible for the organisms present there.
3. What conditions in ecosystems and which activities by human and other animals might affect the number of individuals within each population?
4. How would you measure the change in each population over time?

Figure 1
The size of the various populations in an area, such as those that come to this watering hole, changes over time. Population ecologists have developed a number of methods of quantifying these changes.

Exploration *Moving Populations*

While the populations of many species remain in the same general area all the time, the populations of some species migrate. Each fall, 120 million red land crabs on Christmas Island migrate overland to the coast to mate and lay their eggs (**Figure 2**).

(a) What are the advantages of all the crabs migrating and breeding at precisely the same time each year?
(b) What are the disadvantages to such a strategy?
(c) Each female crab lays about 100 000 eggs, whereas many animal species produce far fewer young. What are the advantages and disadvantages of producing so many offspring? Do you think a high birth rate guarantees population growth?
(d) How might the size of the red crab population fluctuate during the course of a year? Would you expect this pattern to be typical or unusual for wild populations?
(e) If you were a biologist trying to determine if the population was increasing or decreasing over the long term, what challenges would you face?

Figure 2
Red land crabs

22.1 Characteristics of Populations

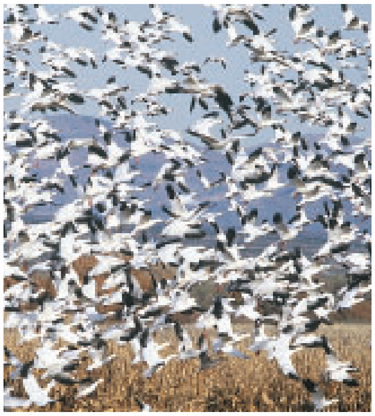


Figure 1
Greater snow geese are endangering their own survival by exceeding the carrying capacity of the natural marshes along the St. Lawrence River during their migration.

Canadian wildlife biologists have expressed concern over the increase in the greater snow goose population in the eastern Canadian Arctic from 50 000 in the late 1960s to about 950 000 in 2004 (**Figure 1**). The presence of increasing numbers of these snow geese has affected other species within the habitat. Overgrazing has caused widespread damage to the vegetation of Arctic coastal sites, resulting in a decline in the abundance of other bird and wildlife species that also depend on these habitats for resources. In the fall, the snow geese migrate south, stopping to feed on agricultural crops in central and eastern Canada and the United States, so many farmers regard the geese as pests. Members of the Arctic Goose Habitat Working Group, a consortium of Canadian and American wildlife biologists, have recommended that, to decrease damage to Arctic ecosystems, the total population of this species be reduced. How do biologists count huge populations of birds that migrate each fall, produce young each spring, and die at different times? How can they determine what population size might be ideal for a particular habitat and how can they tell when a population reaches this ideal size?

Population Size and Density

To study populations, scientists measure such characteristics as **population size**, or the estimated total number of organisms, as well as the density and dispersion of organisms within their habitat. The **population density** (D_p) of any population is calculated by dividing the total numbers counted (N) by the area (A) or volume (V) occupied by the population. For example, the population density of 480 bison living in a 600 hectare (ha) region of Wood Buffalo National Park would be calculated as follows:

population size the number of individuals of a specific species occupying a given area/volume at a given time

population density the number of individuals of the same species that occur per unit area or volume

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

$$D_P = \frac{480 \text{ bison}}{600 \text{ ha}}$$

$$= 0.800 \text{ bison/ha}$$

Populations vary widely among different species occupying different habitats. As shown in **Table 1**, small organisms usually have higher population densities than larger organisms. These widely ranging densities pose different challenges to biologists attempting to gather data on a particular species. Population density can be deceiving because of unused or unusable space within a habitat. For example, the bison in Wood Buffalo National Park do not use areas that are open lake water.

Table 1 Examples of Population Densities

Population	Density
jack pine	380/ha
field mice	250/ha
bison	0.800/ha
soil arthropods	500 000/m^2
phytoplankton (in a pond)	4 000 000/m^3

Learning Tip

You can calculate population density using either area or volume.

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

where D_p is population density, N is number of individuals, and A is area or V is volume

Practice

1. Calculate the density of a population of painted turtles (**Figure 2**) if 34 turtles were counted in a 200 ha park.

Figure 2
A painted turtle

2. Speculate about areas within the park that might not be used by the painted turtles.
3. Suggest a possible proportion (%) of the park that is not used by the turtle. Use the proportion that you think is used by the turtles to calculate a density value. This value is referred to as the **ecological density**.
4. A student counts 56 mosquito larvae in a 2 L sample of water from a local pond. Calculate the density of the mosquito population per litre and per cubic metre of pond water.

ecological density population density measured in terms of the number of individuals of the same species per unit area or volume actually used by the individuals

WWW WEB Activity

Canadian Achievers—Dr. Stephen Herrero

Ecologists use many techniques to determine population size, density, and growth. One such ecologist is Dr. Stephen Herrero, a professor emeritus of environmental science at the University of Calgary (**Figure 3**). Dr. Herrero specializes in wildlife ecology and conservation biology with a special interest in the ecology of large predators—most notably grizzly bears. Learn more about Dr. Herrero and his research on grizzly bears in the eastern Rockies. Write a report or make a presentation that explains how Dr. Herrero uses knowledge of population size, density, and growth to improve grizzly bear management and conservation efforts.

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Figure 3
Dr. Stephen Herrero

Environmental conditions and suitable habitats differ throughout a population's geographic range. For this reason, the **population dispersion** of groups of organisms within a population varies throughout the range. Biologists have identified three main dispersion patterns among wild populations: clumped, uniform, and random. Most populations exhibit patchy or **clumped dispersion**, in which organisms are densely grouped in areas of the habitat with favourable conditions for survival. Cattails exhibit clumped dispersion. They are usually restricted to growing along the edges of ponds and lakes, or in other wet soils. Clumped dispersion may also be the result of social behaviour, such as fish swimming in large schools to gain protection from predators, as shown in **Figure 4** (**a**) on the next page.

population dispersion the general pattern in which individuals are distributed through a specified area

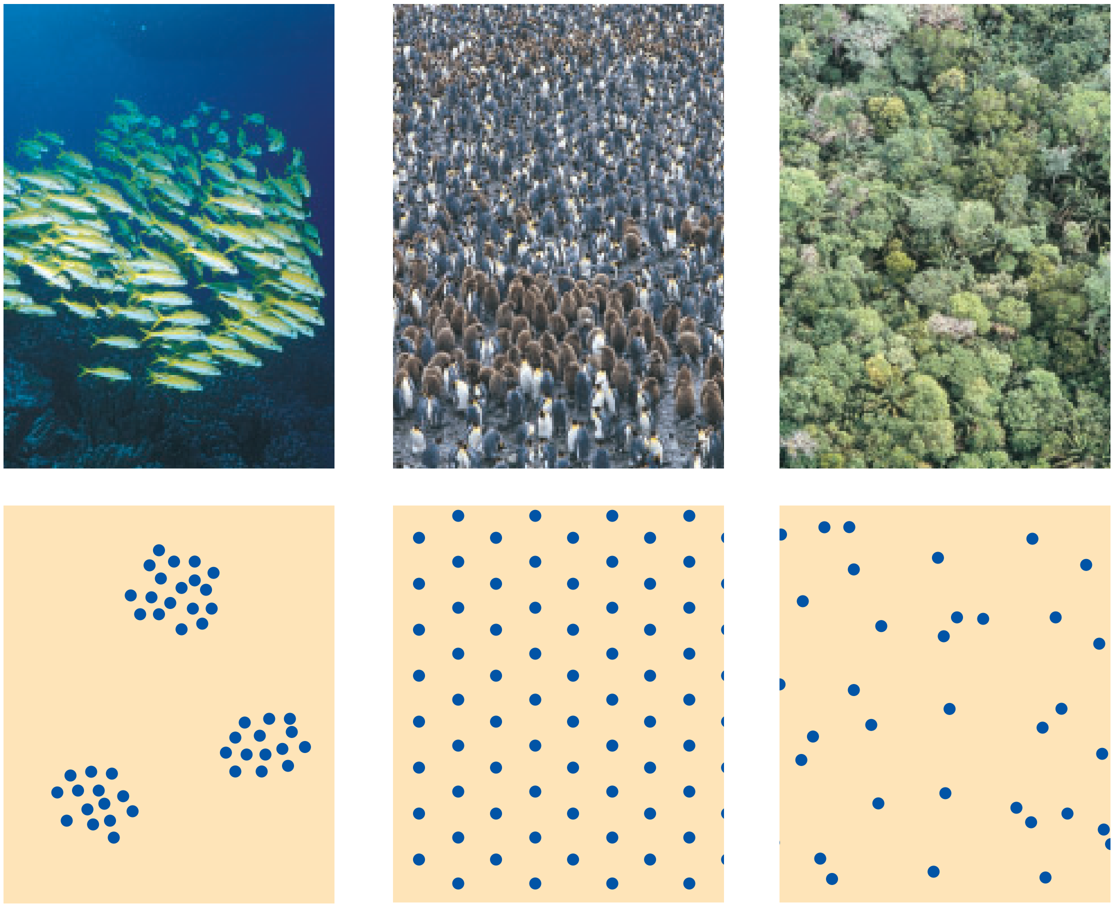
clumped dispersion the pattern in which individuals in a population are more concentrated in certain parts of a habitat

uniform dispersion the pattern in which individuals are equally spaced throughout a habitat

Other organisms exhibit **uniform dispersion** in which individuals are evenly distributed throughout the habitat. This pattern may result from competition between individuals that set up territories for feeding, breeding, or nesting. When King penguins nest on South Georgia Island in the South Atlantic Ocean, they often exhibit a nearly uniform dispersion pattern, as shown in **Figure 4 (b)**. Although wild species rarely exhibit uniform dispersion, the plants in crop fields, orchards, and tree plantations are often uniformly dispersed.

random dispersion the pattern in which individuals are spread throughout a habitat in an unpredictable and patternless manner

Individuals exhibit **random dispersion** when they are minimally influenced by interactions with other individuals and when habitat conditions are also virtually uniform. As shown in **Figure 4 (c)**, some species of trees in tropical rain forests exhibit random dispersion, although this pattern is also rare in nature.



(a) Clumped **(b) Uniform** **(c) Random**

Figure 4

Populations generally exhibit one of three patterns of dispersion:
(a) Yellow goatfish are often found clumped in schools.
(b) Nesting King penguins exhibit a uniform pattern.
(c) In tropical rain forests, trees of the same species may be randomly dispersed.

WWW **WEB Activity**

Case Study—Wildlife Tracking

It is often difficult to determine the range and distribution of wildlife over long periods of time. While many organisms are easy to observe during parts of the year or parts of their life span, they may be very difficult to locate at other times. For example, it is easy to observe sea turtles when they come ashore to lay eggs, but harder to find where they travel and feed in the open ocean. It is easy to observe Alberta's breeding birds in the spring and summer, but much more difficult to determine their migration routes and winter range. Many species pose similar challenges. Beginning in 1937, researchers Fred and Norah Urquhart annually marked monarch butterflies in an attempt to discover the wintering location of this migratory species. In 1975, they finally discovered it.

In this activity, you will conduct research to explore the science of marking and releasing organisms.

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EXTENSION

Mark-Recapture Method

In this animation, you will apply this method of estimating population size to virtual butterflies.

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SUMMARY *Characteristics of Populations*

- Biologists use different measurements, such as population size and population density, to describe and monitor populations.
- Populations in a given geographical range exhibit one of three distinct dispersion patterns: clumped, uniform, or random.

Section 22.1 Questions

1. The Arctic Goose Habitat Working Group recommended that the eastern arctic greater snow goose population be held between 800 000 and 1 million birds by 2002. This reduced population would still be 15 to 20 times greater than the population in the late 1960s.
   (a) What are some consequences of the population remaining so large?
   (b) Discuss some ways in which reductions of geese populations may be achieved.
2. In a group, brainstorm and discuss challenges that biologists encounter in estimating population characteristics for wild populations of
   (a) whales that migrate along the western coasts of North and South America;
   (b) algae that live in water bodies receiving excess fertilizers in runoff from cropland;
   (c) caribou that inhabit an Arctic tundra environment; and
   (d) amphibians that live in marshes.
3. A 1998 study of grizzly bears in the Kananaskis area estimated the population size at 48 to 56 individuals. The study area encompassed 4000 hectares.
   (a) Use these values to determine maximum and minimum density estimates for the population.
   (b) Researchers examined the DNA of hair samples they collected during their field work. How might the analysis of DNA be of value in estimating the size of the bear population?
4. Biologists sometimes measure fish densities using the number of individuals per kilometre of stream. In a study of juvenile bull trout in Eunice Creek, Alberta, the density was observed to increase from less than 50/km in 1984 to over 600/km a year later. Approximately how many more fish were there in 1985 in a section of creek 0.5 km long?
5. The northern leopard frog is one of Alberta's species at risk. It has a highly clumped distribution and is restricted to isolated wetlands supporting very small populations. How might both the isolation and small population sizes of this species threaten its long-term viability?

22.2 Measuring and Modelling Population Change

An ecosystem has finite biotic and abiotic resources at any given time. Biotic resources, such as prey, vary in availability. Some abiotic resources, such as space and light, vary little, while others, such as temperature and water availability, vary greatly. There is, therefore, a limit to the number of individuals that an environment can support at any given time. The carrying capacity of an ecosystem is the maximum number of organisms that can be sustained by available resources over a period of time. You can review these concepts in Chapter 4.

Carrying capacity is dynamic, since environmental conditions are always changing. Two populations of the same species of fish, for example, might occupy quite different ecosystems with different carrying capacities, due to biotic and abiotic variations in the environment. A large, nutrient-poor, oligotrophic lake (**Figure 1 (a)**) could have a smaller carrying capacity per unit area than a much smaller, nutrient-rich eutrophic environment (**Figure 1 (b)**). In this case, the population density of fish in the oligotrophic lake would be much lower than that of the fish in the eutrophic lake.

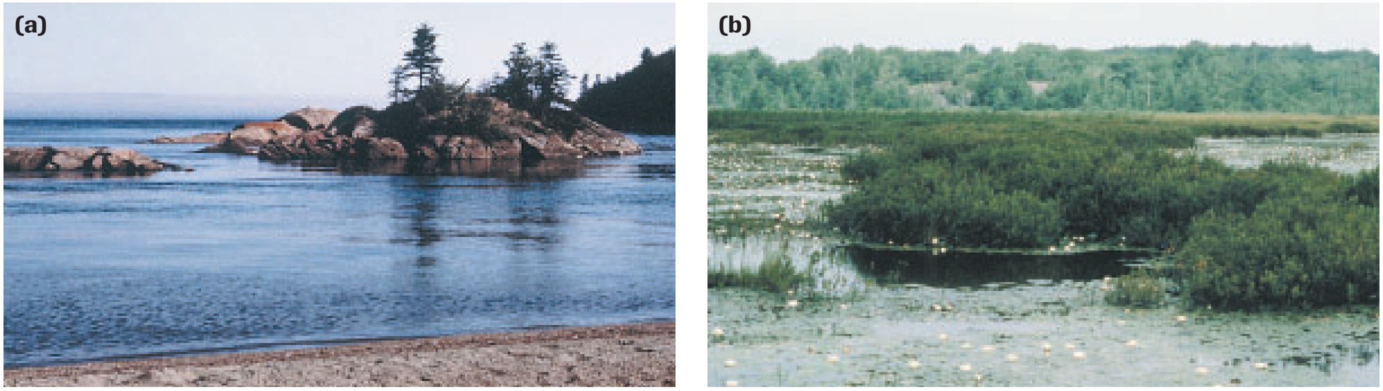

Figure 1
Carrying capacity is determined by the environment in which a population lives. The population size in the oligotrophic lake **(a)** might be limited by available food, while the population size in the eutrophic lake **(b)** might be limited by available space.

When populations increase in size, the amount of resources available per individual decreases. When populations change in density, their new density may exceed the available supply of resources. A variety of factors influences how rapidly populations can grow before they meet or exceed the carrying capacity of their environment.

Factors That Affect Population Growth

Populations are always changing. Depending on the species and on environmental conditions, populations experience natural hourly, daily, seasonal, and annual fluctuations in numbers. Population size can change when individual organisms are added to the population through births or removed through deaths. Population size may also increase when individuals immigrate and decrease when individuals emigrate. The main factors that affect population growth, measured per unit of time, are **natality** (the number of births), **mortality** (the number of deaths), **immigration** (the number of individuals that move into an existing population), and **emigration** (the number of individuals that move away from an existing population). These factors may vary from species to

natality the number of births per unit of time

mortality the number of deaths per unit of time

immigration the number of individuals that move into an existing population per unit of time

emigration the number of individuals that move away from an existing population per unit of time species. For example, the females of some species have the potential to produce very large numbers of offspring in their lifetimes. Each female of many species of starfish, for example, can lay over 1 million eggs per year. In contrast, a female hippopotamus may have the potential to give birth to just 20 young in an entire lifetime of 45 years. For any organism, the maximum reproductive rate that could be achieved under ideal conditions is called the biotic potential. You can review the factors that determine biotic potential in Section 4.4 of this textbook. Biotic potential is an inherited trait, and so can be acted on by natural selection. Human actions can also affect birth, death, immigration, and emigration rates in populations.

DID YOU KNOW?

Biotic Potential

Consider the biotic potential of a single *Escherichia coli* (*E. coli*) bacterium on a hamburger patty. Under ideal conditions, *E. coli* can reproduce by binary fission every 12 min. After 12 min there are two bacterial cells, and after 24 min there are four cells. If this doubling continued unchecked for the next 24 h, there would be enough *E. coli* cells to cover the entire surface of Earth to a depth of more than 1 m!

Determining Changes in Population Size

Population ecologists often need to quantify changes in population growth in order to monitor and evaluate these changes. Mathematical models provide the underlying foundation for this science.

The number of individuals in a population is given by the variable ***N***. The change in the number of individuals in a population, **ΔN**, can be calculated from natality, mortality, immigration, and emigration, using the following equation:

$$\Delta N = [\text{natality } (n) + \text{immigration } (i)] - [\text{mortality } (m) + \text{emigration } (e)]$$

N a variable describing the number of individuals in a population

ΔN a variable describing the change in the number of individuals in a population

If the number of births plus immigrants is higher than the number of deaths plus emigrants, the population will have positive growth, increasing in size. Conversely, if the number of deaths plus emigrants exceeds the number of births plus immigrants, the population will experience negative growth, decreasing in size. If the number of births plus immigrants equals the number of deaths plus emigrants, the population is said to have zero growth and will remain a constant size.

While measuring ΔN is of great value, population ecologists are often more interested in the **growth rate (*gr*)**, which describes how quickly a population is increasing or decreasing—the change in population size per unit of time. The population growth rate is given by the formula:

$$gr = \frac{\Delta N}{\Delta t}, \text{ where } \Delta t \text{ represents the change in time (often measured in years)}$$

growth rate (*gr*) the change in population size per unit of time

The growth rate is often expressed as a **per capita growth rate (*cgr*)** and represents the change in population size, ΔN, relative to the initial population size, N.

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

per capita growth rate (*cgr*) the change in population size relative to the initial size of the population, per unit time

The usefulness of per capita growth rate is clear when comparing populations of different sizes. For example, a population of 2000 individuals that grows by 40 in 1 year has a growth rate of 0.020, while a smaller population of only 200 individuals, with the same increase in numbers (40), experiences a dramatic growth rate of 0.20. Per capita growth rate may also be expressed as a percentage, by multiplying it by 100 ($cgr \times 100$).

SAMPLE exercise 1

Over 2 years, a population of 900 experienced 66 births and 14 deaths. Five individuals left the population and 13 individuals joined the population. Using this information, determine

(a) the population change

(b) the new population size

(c) the growth rate

(d) the per capita growth rate

Solution

(a) We are given the following variables:

change in time, $\Delta t = 2$ years

initial population size, $N = 900$ individuals

natality, $n = 66$ individuals

immigration, $i = 13$ individuals

mortality, $m = 14$ indiviuals

emigration, $e = 5$ individuals

The required variable is population change, ΔN. It can be determined from equation

$$\begin{aligned}\Delta N &= [(n) + (i)] - [(m) + (e)] \\ &= [66 \text{ individuals} + 13 \text{ individuals}] - [14 \text{ individuals} + 5 \text{ individuals}] \\ &= 60 \text{ individuals}\end{aligned}$$

The population change, ΔN, is 60 individuals.

(b) From the given information, we know that the initial population size, N, was 900 individuals. We determined the change in population size, ΔN, in part (a). The new population size is the sum of these values.

$$\begin{aligned}N + \Delta N &= 900 \text{ individuals} + 60 \text{ individuals} \\ &= 960 \text{ individuals}\end{aligned}$$

The new population size is 960 individuals.

(c) The required variable is growth rate, gr. We know the change in time, Δt, from the given variables. We determined the change in population size, ΔN, in part (a). The growth rate is determined from the equation

$$\begin{aligned}gr &= \frac{\Delta N}{\Delta t} \\ &= \frac{60 \text{ individuals}}{2 \text{ years}} \\ &= 30 \text{ individuals/year}\end{aligned}$$

The growth rate is 30 individuals per year.

(d) The required variable is per capita growth rate, cgr. We were given the initial population size, N. We determined the change in population size, ΔN, in part (a). The per capita growth rate is determined from the equation

$$\begin{aligned}cgr &= \frac{\Delta N}{N} \\ &= \frac{60 \cancel{\text{ individuals}}}{900 \cancel{\text{ individuals}}} \\ &= 0.067\end{aligned}$$

Learning Tip

When solving a problem involving a calculation, a good strategy is to start by identifying the given variables and the required variable.

Learning Tip

Exact numbers, like the number of individuals in this question, are considered to have an infinite number of significant digits. You can review the rules for determining significant digits in Appendix A7, Math Skills.

Since the population change took place over 2 years, then the per capita growth rate is 0.067 per 2 years. To get the per capita growth rate per year, we therefore must divide 0.067 by 2.

$$\frac{0.067}{2 \text{ years}} = 0.0335 \text{ per year}$$

The per capita growth rate per year is 0.0335.

Practice

1. Complete **Table 1** by calculating the missing values.

Table 1 Measured and Calculated Factors Describing Four Different Populations

	Initial population (*N*)	Time period (Δt)	Births (*n*)	Deaths (*m*)	Immigrants (*i*)	Emigrants (*e*)	Population change (ΔN)	Growth rate (*gr*)	Per capita growth rate (*cgr*)
(a)	600	2	20	15	25	10			
(b)	200	4	40	60	10	0			
(c)	3000	1	450	350		100	150		
(d)	1000		180	160	30	40		5	

2. The human population has a per capita growth rate of approximately 0.012 per year. If the human population is 6 billion, determine
(a) the change in population per year
(b) the change in population per day

Population Growth Models

Scientists studying wild populations often use such mathematical models, based on data collected in the field. Models can provide a visual tool to help researchers see patterns in past population changes and predict future population change. For example, population ecologists may use plots of the past growth rate of a population over time to predict future increases or decreases in the population of a species at risk.

The growth of a population also depends on whether the population is open or closed. An **open population** refers to a population that is influenced by the factors of natality, mortality, emigration, and immigration. Most wild populations are open, since they have the ability to immigrate and emigrate between populations that exist in different locations. In a **closed population** immigration and emigration do not occur so only natality and mortality determine population growth. Closed animal populations are rare. Land-based populations on secluded islands, such as the Peary caribou herd that inhabits an Arctic Ocean island, can be thought of as closed because they have no easy means to travel to other populations. (The animals are able to move between islands in winter.)

We will explore two common models of population growth, exponential growth and logistic growth. For both these models, it is assumed that immigration is equal to emigration, so only natality and mortality are considered. This would be similar to a closed population.

When a population increases by **exponential growth**, the population size increases by a fixed rate over a fixed time period. This rate is denoted by the variable ***r***. A population will only grow exponentially when its ecosystem has an unlimited supply of the biotic and abiotic resources it needs, such as food, light, space, and water. Under these

open population a population in which change in number and density is determined by natality, mortality, immigration, and emigration

closed population a population in which change in size and density is determined by natality and mortality alone

exponential growth a pattern of population growth in which the population size increases by a fixed rate per a fixed unit of time

r a variable indicating the rate of increase of a population experiencing exponential growth; *r* is limited only by the biotic potential of the organisms in the population conditions, the only limit on population growth is the biotic potential of the individuals making up the population.

During exponential growth, natality is always higher than mortality. Therefore, each successive generation of a population will have more individuals and more offspring than the previous generation. For example, let's assume that the initial size of a yeast cell population is 3000 yeast cells and that 10 % of the cells die each generation. The cells in the starting population divide to produce 6000 offspring, of which 600 die. Reproduction of the remaining 5400 cells gives 10 800 offspring, of which 1080 die. The next generation would then be 21 600 cells, of which 2160 would die, and so on. You can see how population size increases very rapidly during exponential growth. When population size versus time is plotted for a population undergoing exponential growth, the resulting graph is always J-shaped, as shown in **Figure 2**. Therefore, if a researcher has data that gives a J-shaped curve, she or he knows that the population is growing exponentially.

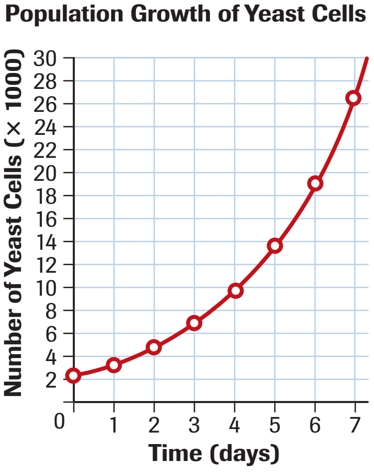

Figure 2
Exponential growth curves are always J-shaped.

Notice that in **Figure 2**, the exponential growth curve is smooth. This is because yeast cells reproduce throughout the year, as do many other species (including humans). However, many species reproduce only at a particular time of the year. For example, harbour seals in northern British Columbia breed only between May and June. In these species, population size typically increases very quickly during the breeding season and then drops. Therefore, population size must be measured at the same time each year (such as June of each year) to accurately determine population size changes. If the ratio between natality and mortality remains constant, the size of the population will increase in steps over time (**Figure 3 (a)**).

EXTENSION

Population Growth Curves
Listen to this discussion of why population size increases gradually during the early stages of a population's growth.

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Population biologists are often more interested in long-term growth patterns than in short-term seasonal fluctuations. Population growth graphs for species that reproduce only at specific times are therefore usually drawn as smooth curves, which show changes in average population size over time (**Figure 3 (b)**).

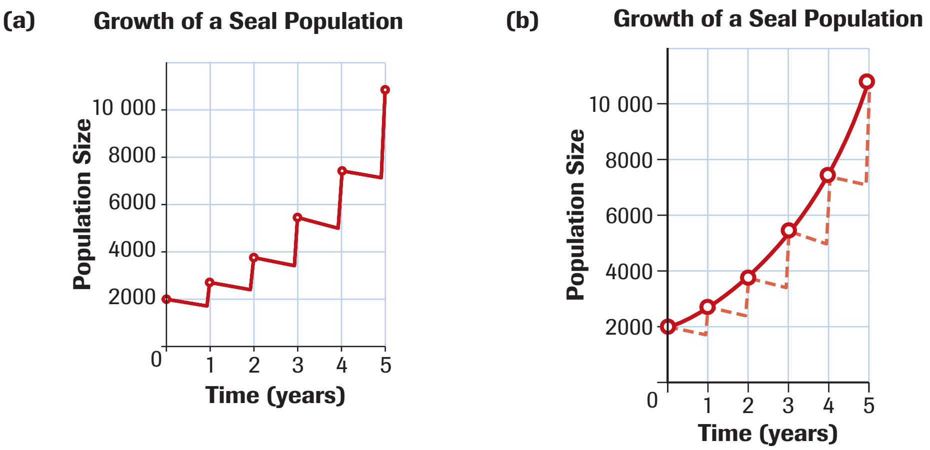

Figure 3
(a) The size of the seal population size was determined several times each year. There are sharp increases when reproduction occurred, followed by declines in numbers.
(b) Drawing the graph as a smooth curve shows the long-term trend in average population size.

For any population growing exponentially, the time needed for the population to double in size is a constant. The **doubling time** (t_d) of the population can be estimated by the following formula:

doubling time (t_d) the time needed for a population that is growing exponentially to double

$$t_d = \frac{0.69}{cgr}$$

The value 0.69 is a constant. For example, if a population has a per capita growth rate of 2.0 % per year (0.020), the approximate time needed for the population to double would be $\frac{0.69}{0.020}$, or 35 years (to two significant digits).

SAMPLE exercise 2

A population of 2500 yeast cells in a culture tube is growing exponentially. If the per capita growth rate, *cgr,* is 3.0 % per hour, calculate

(a) the time it will take for the population to double in size

(b) the size of the population after each of four doubling times

Solution

(a) We are given the following variables:

number of individuals, $N = 2500$ individuals

per capita growth rate, $cgr = 3.0$ % or 0.030 per hour

The required variable is population change, t_d. It can be determined from equation

$$t_d = \frac{0.69}{cgr}$$

$$= \frac{0.69}{0.030 \times \frac{1}{\text{hour}}}$$

$$= 23 \text{ hours}$$

The yeast population will double in size every 23 hours.

(b) The size of the population after four doubling times can be determined using a table, as shown in **Table 2**.

$t_d = 23$ hours, initial population size is 2500

Table 2 Change in Yeast Cell Population Size

Doubling times	Time (hours)	Population size
0	0	2500
1	23	5000
2	46	10 000
3	69	20 000
4	92	40 000

Practice

3. After the rainy season begins in the tropics, a small population of mosquitoes exhibits exponential growth. The initial population size is 980 and the per capita growth rate is 34.5 % per day.

(a) Calculate the doubling time for the population.

(b) How many doubling times will have to pass in order for the population to exceed 2 000 000? How many days is this?

CAREER CONNECTION

Ecologist

Ecologists study a wide range of subjects, all of which involve the relationships of living organisms to each other and to their environments. Ecologists are often particularly interested in population size and population growth characteristics. Ecologists plan and conduct field research and long-term studies to find life history patterns, and develop recommendations on wildlife management. Are you interested in a career as an ecologist?

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Learning Tip

Remember to follow the rules for significant digits in your answers. You can review these rules in Appendix A7.

environmental resistance any factor that limits a population's ability to realize its biotic potential when it nears or exceeds the environment's carrying capacity

logistic growth a model of population growth describing growth that levels off as the size of the population approaches its carrying capacity

lag phase the initial stage in which population growth rates are slow as a result of a small population size; characteristic of geometric, exponential, and logistic population growth

log phase the stage in which population growth rates are very rapid; characteristic of geometric, exponential, and logistic growth

stationary phase the phase in which population growth rates approach zero as the population size reaches the carrying capacity and stabilizes; the defining characteristic of logistic population growth

K a variable indicating the number of individuals in a population at the carrying capacity of an environment

The exponential model of population growth assumes that a population will continue to grow at the same rate indefinitely. This implies that the population has continuous access to an unlimited supply of resources. Of course, an unlimited resource supply is never the case in the real world. Any ecosystem has a limited supply of biotic and abiotic factors to support the organisms in it. Eventually, resources will become scarce.

However, when a population enters a new ecosystem, abiotic and biotic resources are often plentiful. Initially, there may be only a few individuals, so the initial growth rate may be slow. However, since population growth isn't limited by resources, the population size will increase exponentially. Eventually, however, the population size will approach the carrying capacity of the ecosystem, and resources such as food, water, light and space will begin to limit population growth.

The influence of biotic and abiotic factors that limit the size of a population is called **environmental resistance**. As environmental resistance increases, the growth rate of the population slows until natality and mortality become about equal. At this point, the size of the population stabilizes. This pattern of population growth is called **logistic growth**. This model of population growth fits most closely with population growth patterns seen in nature.

If you graph logistic growth, the curve resembles the letter S. As a result, it is referred to as an S-shaped or sigmoidal curve, which has three distinct phases (**Figure 4**). The first, called the **lag phase**, occurs when the population is small and is increasing slowly. The second phase, called the **log phase**, occurs when the population undergoes exponential growth. As available resources become limited, the population experiences increasing environmental resistance and cannot continue rapid growth; therefore, the population's reproduction slows and the number of deaths increases. This is the **stationary phase**, which occurs at or close to the carrying capacity of the environment. The size of the population when it has reached the carrying capacity is indicated by the variable ***K***. At the stationary phase, a population is said to be in dynamic equilibrium, because the number of births equals the number of deaths, resulting in no net increase in population size.

Logistic growth can be seen in a population of fur seals on St. Paul Island, Alaska. In 1911, fur seal hunting was banned since the population had become extremely low. Since their numbers were so low, the seals had many unused resources to support the recovering population. The population grew rapidly until it stabilized around its carrying capacity, as shown on **Figure 5** on the next page.

EXTENSION

Factors Contributing to the End of Exponential Growth

Why does exponential population growth end? Find out more by listening to this description of what happens as a population nears the carrying capacity and its rate of growth slows.

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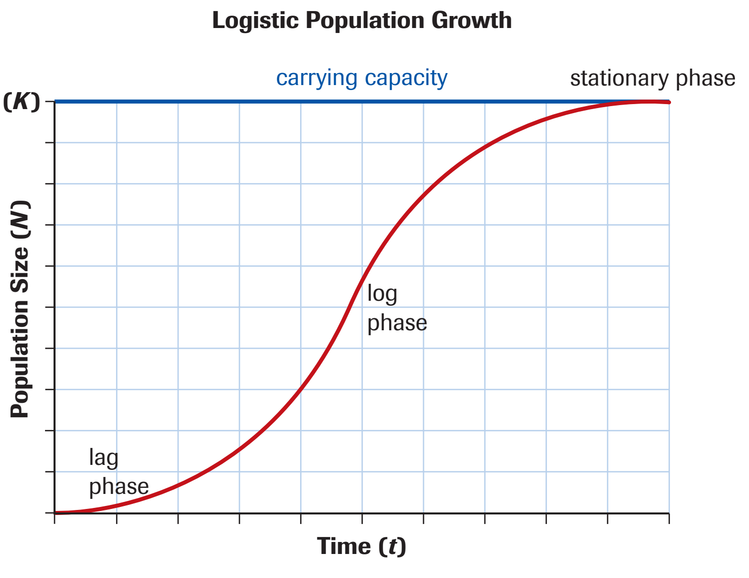

Figure 4
The logistic growth model results in a sigmoidal (S-shaped) curve.

The logistic growth model works for populations growing under suitable conditions, but fits few natural populations perfectly for two main reasons: no population exists by itself, and many interactions occur among the members of a single population.

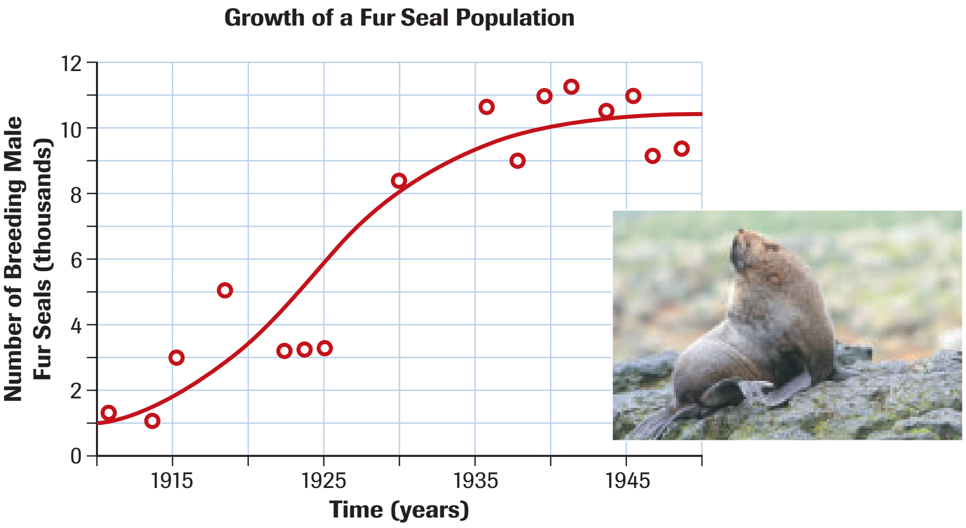

Figure 5
A population graph from 1910 to 1950 for fur seals on St. Paul Island, Alaska

mini Investigation

Blogs in a Bottle: Population Growth in a Finite Environment

The size of most populations fluctuates over short periods, but remain relatively stable over long periods of time. However, under certain environmental conditions, populations may be able to grow steadily and often rapidly. Such populations eventually reach or exceed the carrying capacity of their environments and their growth ceases.

In this activity, you will model the growth of an imaginary population that lives in a large but finite environment. The Blog population has a constant *cgr* and doubles in size every five days. Blogs can only live in a bottle.

Materials: water (Blogs), eye dropper, graduated cylinders (small and large), large bottle

Predict the number of doubling times it will take for the population of Blogs to completely fill their bottle (reach their maximum sustainable population size).

- Place the starting population (one drop of water) in the bottle. Record the population size in a data table.
- Add a second drop of water to represent the passing of five days. Record the time and total population size.
- Add enough water to again double the total size of the population. Record your values.
- Repeat the above step until the bottle is completely full or you have run out of time.

Note: When the total population size reaches 16 drops, you may convert your measurements to millilitres. One millilitre is roughly equivalent to 16 drops.

(a) Plot a graph of population size versus time. If you have access to a spreadsheet program, use it to tabulate your data and generate the graph.

(b) How many doubling times did it take for the Blogs to completely fill their bottle?

(c) Was your prediction/hypothesis correct? Were you surprised by the results?

(d) If the Blogs found three new environments—three similar empty bottles—how many more doubling times would it take to completely fill all four bottles?

(e) Examine your graph. During what span of time would the Blogs not have worried about running out of space? In other words, when do you think the Blog population might have first realized they had little time left at their current growth rate?

SUMMARY Measuring and Modelling Population Change

- Mathematical models are used to predict trends in population growth.
- Exponential growth demonstrates growth limited only by biotic potential.
- Logistic growth, limited by carrying capacity, is most like the population growth patterns seen in wild populations.

Section 22.2 Questions

1. Researchers studied a population of 34 peregrine falcons for one year to analyze the effect of pesticides on population growth. In the first three months, 57 eggs were laid. Owing to thin shells suspected to have resulted from pesticide damage, 28 eggs broke. Of the remainder, 20 hatched successfully (**Figure 6**). However, nine baby falcons died from severe birth defects. During the next 6 months, 11 birds died as a result of direct pesticide exposure, and 8 were captured and taken to a conservation area. During the last three months, four birds migrated into the area. Determine the population growth of peregrine falcons in this study.

Figure 6

2. The growth rate for a population of 90 field mice in 6 months was 429 %. If the number of births was 342, the number of deaths was 43, and there was no emigration, determine the number of mice that migrated into the field.
3. In practising both agriculture and forestry, humans attempt to maximize productivity of the plants they are harvesting. For example, the application of herbicides on crops and tree plantations helps reduce competition from other plant species. Describe additional ways in which farmers and foresters help domesticated and harvested species approach their biotic potential.
4. In many rural areas, stray cats are a problem as they may return to being wild (also known as feral). Feral cats that have not been spayed or neutered can reproduce, which may result in a population of feral cats. One pair of cats can produce 12 kittens in 1 year. If half these kittens are female, this increased population could potentially produce 84 kittens in the second year. In 5 years, the population could reach almost 33 000 feral cats.
   (a) Identify the kind of growth that is occurring.
   (b) Outline the conditions that would have to be in place for the population to achieve its biotic potential.
   (c) Describe various types of environmental resistance that might restrict the feral cats from reaching their biotic potential.
5. A biologist determines the growth rate of a population of 198 frogs in a marsh near Beaverhill Lake, Alberta, to evaluate the quality of the environment. The researcher finds that, in one year, 34 were born, 86 died, 12 migrated into the marsh, and there was no emigration.
   (a) Determine the growth rate, *gr*, and the per capita growth rate, *cgr*, of the population.
   (b) Do you think that tracking the population growth rate of one population of frogs over one year in this marsh is adequate to make a conclusion about the environment? Explain your reasoning.
6. Scientists monitored the population size of a species newly introduced to an ecosystem. Their data are in **Table 3**.

Table 3 Population Size of Species X

Year	Population size	Year	Population size
1999	44	2003	301
2000	56	2004	275
2001	132	2005	321
2002	224	2006	298

   (a) Sketch a graph of the data. Identify the form of growth curve of the species.
   (b) Predict the long-term impact on population size if a second group of 44 individuals were added to this population in 2007.
   (c) Use your graph to estimate the number of individuals in the whole population when it has reached the carrying capacity of the ecosystem (*K*).

Factors Affecting Population Change 22.3

In 1993, zebra mussel populations in the lower Illinois River, which had exploded to a density of nearly 100 000 per square metre, were causing significant harm to aquatic ecosystems. The zebra mussels were severely depleting the amount of dissolved oxygen available to the entire ecosystem, and increasing competition for food resources. The resulting conditions were stressful for other species, but also affected the survival of the zebra mussels. Scientists observed a dramatic decline in these populations. Researchers now believe that the increased density of the zebra mussel population led to increased competition among members of the population (**Figure 1**).

Figure 1
Competition for resources among zebra mussels will eventually limit growth in these populations.

Density-Dependent Factors

With an increase in population size—for example, after young are born—the population density of the species increases. High density results in adverse conditions. Some individuals may find it difficult to obtain food and may emigrate. Others may die. A factor that affects a population only when it has a particular density is called a **density-dependent factor**. Such a factor limits population growth. Charles Darwin recognized that the struggle for available resources within a growing population would inherently limit population size. This struggle for survival involves such factors as competition, predation, disease, and other biological effects.

density-dependent factor a factor that influences a population at a particular density

intraspecific competition an ecological interaction in which individuals of the same species compete for resources in their habitat

When the individuals of the same species rely on the same resources for survival, **intraspecific competition** occurs. As population density increases, intraspecific competition increases, so the population's growth rate slows. This intraspecific competition can have a pronounced effect on the reproductive success of individuals, as shown in the example in **Figure 2**. As competition for food increases, the amount of food per individual often decreases. This decrease in nutrition results in a decrease in an individual's growth and reproductive success. Harp seals, for example, reach sexual maturity when they have grown to 87 % of their mature body weight. When the population density increases, each individual seal gets less to eat and gains weight more slowly than it would if the population density were lower. As a result, the seals reach sexual maturity at a slower rate, which decreases the potential number of offspring they might have.

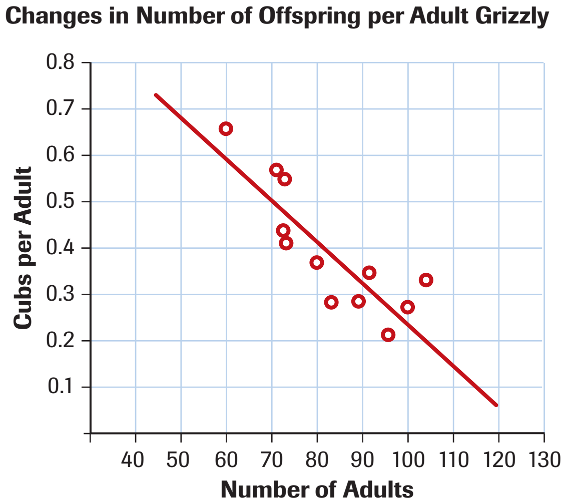

Figure 2
As population density increases in this grizzly bear population, the number of cubs per adult decreases.

predation an ecological interaction in which a predator (a member of one species) kills and consumes prey (usually a member of another species)

minimum viable population size the smallest number of individuals needed for a population to continue for a given period of time

Figure 3
Minimum viable population size is only a prediction. The whooping crane did not become extinct, even when there were only 23 birds left.

density-independent factor a factor that has the same influence on a population at any population density

Figure 4
Swainson's hawks are decreasing in numbers as a result of pesticide use.

Another major density-dependent factor that limits population growth is **predation**, the consumption of prey by predators. If a prey species has a large, dense population, intense competition for limited food may result in individuals with poorer health. These individuals are easier for the predator species to catch.

Disease can also be a significant density-dependent factor that limits population size. In dense or overcrowded populations, pathogens are able to pass more easily from host to host. The population declines in size as a result of increased mortality. The overcrowding of farm animals can lead to the spread of disease, such as foot-and-mouth disease in cattle and avian flu in poultry. In 2000, in the *Proceedings of the National Academy of Science*, researchers Wesley M. Hochachka and André A. Dhondt reported the spread of a common poultry pathogen, *Mycoplasma gallisepticum*, in North America through the house finch, *Carpodacus mexicanus*. They showed a relationship between population size and the incidence of the disease, concluding that the spread of this disease was density-dependent.

Some density-dependent factors reduce population growth rates at low densities. A small population size can result in inbreeding and the loss of genetic variation, which can threaten a population's continued survival. The **minimum viable population size** is the smallest number of individuals that ensures the population can persist for a given amount of time. The minimum viable population size consists of enough individuals so that the population can cope with variations in natality and mortality as well as environmental change or disasters. The minimum viable population size varies among species. Scientists use it as a model to estimate the size at which a population would be considered at risk. In 1941, biologists were concerned that the whooping crane would become extinct, since the wild population worldwide had decreased to 21 birds, and only two birds were in captivity (**Figure 3**). Hunting of the birds for meat and eggs, as well as disturbance of their wetland habitats in Wood Buffalo National Park in Canada and along the Texas coast in the United States, had reduced the number of whooping cranes to well below the minimum viable population size predicted by biologists. An ambitious breeding program, along with legal protection of the whooping crane and its winter and summer habitats, have restored the population of wild and captive birds to nearly 300, although the species is still considered endangered.

Density-Independent Factors

Populations may also experience changes in size that are not related to population density. **Density-independent factors** can limit population growth through changes in environmental conditions. For example, certain species of thrips, a small insect considered a common plant pest, feed on so many plant species that food supply is rarely a limiting factor. Cooler temperatures, however, reduce the reproductive success of these species. With a reduced birth rate, the population size declines. With the return of warmer temperatures, reproductive success improves and populations expand once again.

Insecticide application is a density-independent factor caused by human actions. The lethal effects of the pesticide exist whether the population has two organisms or two million. Swainson's hawks migrate between the grasslands of the Canadian prairies and Argentina (**Figure 4**). Wildlife biologists noted a drastic decrease in the population of these birds throughout North America, but had not found the cause. It was suspected that many of these hawks hunted for insects, mostly grasshoppers, in farmers' fields. Argentinian fields were regularly sprayed with highly toxic pesticides to control the grasshopper population and preserve the crops for human food. These particular pesticides are banned in North America.

In 1996, 12 Swainson's hawks were captured in Alberta and tagged with satellite transmitters before they migrated to Argentina. Biologists flew to the migration destination to observe the tagged birds and counted more than 5000 dead hawks, killed from pesticide exposure either directly or through the food chain. Some of the pesticides have now been banned in Argentina, and the numbers of Swainson's hawk are beginning to recover.

Limiting Factors and Population Size

Any environmental factor, whether it is density-dependent or density-independent, can be the limiting factor of an ecosystem. Of all the resources that a population requires for growth, the resource in shortest supply is called the limiting factor, and it determines how much the population can grow. For example, a plant population requires nitrogen, carbon dioxide, and sunlight in order to grow (**Figure 5**). If it uses up all available nitrogen, it can no longer grow, even if there is still an abundance of sunlight and carbon dioxide. In this case, nitrogen is the limiting factor. Limiting factors prevent populations from achieving their biotic potential, and determine the carrying capacity of the populations.

(a) **(b)**

Figure 5
Plants need many different resources for growth and survival. The resource in shortest supply is considered the limiting factor to growth. The orange hawkweed plants in **(a)** are flourishing while the plants in **(b)** are limited by available space.

EXTENSION

Population Biology
In this Virtual Biology Lab, you can manipulate variables to explore the relationships between population size, environmental carrying capacity, birth rate, and death rate in a population.

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INVESTIGATION 22.1 *Introduction*

Measuring Population Changes

Duckweed is a tiny flowering plant that floats in clusters on the surface of freshwater ponds. In this investigation, you will design and conduct experiments to test the influence of environmental factors on the growth rate of a duckweed population. You will also estimate the carrying capacity of the environment.

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

To perform this investigation, turn to page 758.

EXPLORE *an issue*

Issue Checklist

○ Issue ● Resolution ○ Design ● Evidence ● Analysis ● Evaluation

Carrying Capacity Changes in a Warm Arctic

In February 2005, Alexander Wolfe and Neal Michelutti, researchers at the University of Alberta, published their findings on climate change. As part of a 16-member team of scientists from Canada, Norway, Finland, and Russia, the researchers studied changes to populations of microscopic algae and primary consumers in the High Arctic and came to the conclusion that "the biology is starting to change."

Canada's Arctic landscape is one of the most beautiful, pristine, and harsh environments on Earth. Species diversity is limited, many population sizes are small, and population densities are often low. The extremely cold winters, shifting pack ice, and permafrost have all been major limiting factors that have prevented the vast majority of species from inhabiting this vast ecosystem. Meanwhile, these same physical conditions have created an environment in which a very special group of species has evolved. Polar bears, arctic poppies, arctic char, and narwhals all call the Arctic their home. These species and many others survive the long harsh winters and reproduce successfully during the long summer days. The Arctic is also home to Inuit, who have flourished in this environment for thousands of years.

But this environment is changing: the Arctic is warming. Until recently, most of the attention regarding climate change and global warming has focused on physical data—temperature changes, pack ice and permafrost melting, sea-level changes, and changing weather patterns. Now, data and observations are emerging that highlight the impacts on living systems (**Table 1**).

1. Suggest one or more specific environmental limiting factors that may be responsible for each of the changes shown in **Table 1**.
2. When an environmental factor changes, is the result always detrimental to living organisms?
3. Why are major environmental changes more likely to benefit species that do not normally live in the region, and more likely to harm species that are native to the region?
4. Populations of many Arctic species are small and have low densities. How might these factors make them more vulnerable to change?
5. Conduct library and Internet research to become more aware of the impact of climate change on Inuit in Canada. How does climate change threaten their traditional way of life?

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Table 1 Observed Changes in Populations Living in Arctic Regions

Species	Changing population parameters
ivory gulls	Rapid and dramatic 80 % decline in populations nesting in the High Arctic.
various	Expanding home ranges. Insects such as the yellow jacket wasp, mammals including cougar and mule deer, and birds such as the rose grosbeak and dusky flycatcher are all appearing in northern communities for the first time.
insect pests	The spruce bark beetle has devastated 300 000 ha of forest in Canada's Kluane National Park, Yukon. The spruce budworm now appears only 400 km south of the Arctic circle.
trees	Trees are growing faster, as evidenced by thicker tree rings in trees sampled in the Mackenzie River delta.
polar bears	Reductions in pack ice are forcing polar bears to swim farther to reach their seal-hunting grounds. Some scientists predict that summer pack ice may be completely gone in a matter of decades.

Environmental Stability and Population Change

The amount of change in an ecosystem also affects the growth of populations. In a stable ecosystem, the amounts and types of abiotic and biotic factors remain very similar over time. Undisturbed boreal forests, such as can be found in Jasper National Park, are stable ecosystems. In unstable ecosystems, factors in the ecosystem undergo rapid, unpredictable change. A boreal forest that is being logged is an example of an unstable ecosystem. Different organisms have different reproductive strategies, and natural selection favours different strategies in these two types of ecosystems.

Recall from the previous section that K is the number of individuals in a population at the carrying capacity of its ecosystem. ***K*-selected organisms** have traits that adapt them to living in a population at or near to the carrying capacity of their ecosystem. They are most often found in a stable environment. The most significant trait of K-selected organisms is their reproductive strategy. They produce only a few offspring and devote large amounts of parental resources ensuring those offspring survive. K-selected organisms are usually large, with long life-spans. Their offspring tend to be slow-growing and require a lot of parental care. They have a low biotic potential, so the size of populations of K-selected organisms tends to change slowly. When the number of K-selected organisms in an ecosystem becomes too high, competition between individuals soon becomes intense, reducing the survival rate and limiting the number of adults available to breed. The overall population is therefore maintained close to the carrying capacity. Large mammals such as elk, bears, and humans are K-selected species (**Figure 6 (a)**).

***K*-selected organism** an organism that is adapted to survive at or near the carrying capacity of its environment

The variable r represents the rate of increase of a population experiencing exponential growth. The genetic traits of ***r*-selected organisms** allow them to increase their population size rapidly. These organisms are most often found in unstable environments. The reproductive strategy of r-selected organisms is to produce many offspring and devote very little parental resources to their survival. They are usually small in size, have a short life-span, and have a high biotic potential. When environmental conditions are favourable, a population of r-selected organisms can grow very quickly, with competition not usually being a significant factor. Conversely, a change to unfavourable environmental conditions can result in deaths. Many insect species are r-selected organisms (**Figure 6 (b)**).

***r*-selected organism** an organism that is adapted to increase population size rapidly

(a)

(b)

Figure 6

(a) Humans are *K*-selected organisms. Each individual is capable of producing relatively few offspring and invests a lot of time and resources in their care.

(b) Mosquitoes are *r*-selected organisms. Each individual is capable of producing hundreds of offspring, and invests little in their care.

CAREER CONNECTION

College, Technical, or Vocational Instructor

Studying population change and community dynamics requires many technical skills. Much of this training can be gained at a college or a technical or vocational institution. Instructors at these schools teach various subjects, including hands-on laboratory and research techniques. If you enjoy the idea of combining skills in science with teaching and training, this may be a good career for you.

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The general characteristics of these two classes of organisms are summarized in **Table 2**.

Table 2 General Features of *K*-selected Species and *r*-selected Species

***K*-selected species**	***r*-selected species**
live in predictable, stable environments	exploit rapidly changing environments
long-lived	short-lived
population size stable	population size highly variable
density-dependent mortality	density-independent mortality
competition intense	competition low
multiple reproductive events beginning later in life	single reproductive event at a young age
prolonged parental care of young	little or no parental care of young
modest numbers of offspring	very high numbers of offspring
tend to have an S-shaped population growth curve	tend to have a J-shaped population growth curve
large body size	small body size

SUMMARY Population Change

- Density-dependent factors affect a population only at particular population densities.
- The influence of density-independent factors is the same regardless of population density.
- *K*-selected organisms tend to be found in stable environments. Their reproductive strategy is to produce fewer offspring and devote significant parental resources to ensure their survival.
- *r*-selected organisms tend to be found in unstable environments. Their reproductive strategy is to produce many offspring and devote few parental resources to them.

Section 22.3 Questions

1. Explain the difference between density-dependent and density-independent factors.
2. Classify the following scenarios as density-dependent or density-independent:
   (a) A forest fire destroys a great deal of habitat in Jasper National Park.
   (b) Many aquatic organisms die as a result of adverse weather conditions during the breeding season.
   (c) A young aggressive hawk invades the geographic range of established hawks, driving weaker birds from the geographic range.
3. Identify one density-dependent and one density-independent limiting factor that were not discussed in this section. Explain how they might affect the growth of a population.
4. Differentiate between *r* and *K* population growth strategies. Give at least two examples of each.

5. Study the graph in **Figure 7** which shows a population of the great tit, a European bird similar to the chickadee. The graph illustrates population density versus clutch size (the number of eggs to be hatched at one time).
   (a) Is this a case of density-dependent or density-independent regulation?
   (b) Draw a corresponding graph to illustrate population density versus food supply. Explain the reasoning behind the shape of your graph.
6. For each example in **Figure 8**, determine whether the population is made up of *r*-selected organisms or *K*-selected organisms. Justify your answer using the characteristics listed in **Table 2**.

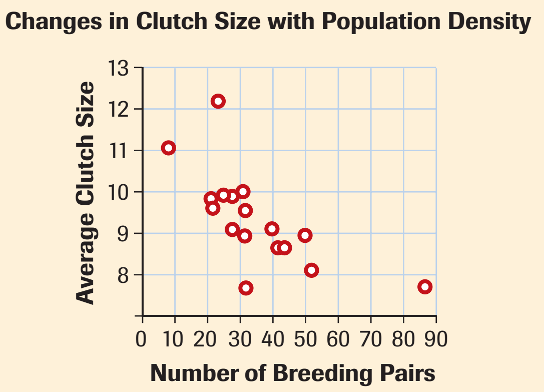

Figure 7

(a) Galapagos tortoise

(b) pioneer succession plant species or large insect swarm

(c) rabbit

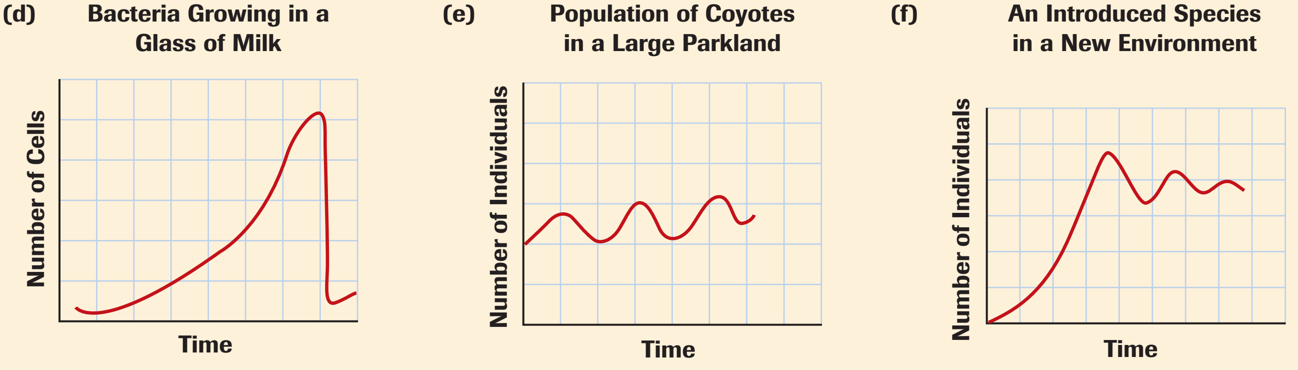

Figure 8

INVESTIGATION 22.1

Measuring Population Changes

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

Duckweeds, among the smallest of all flowering plants, are free-floating, aquatic plants that form green mats on the surfaces of freshwater ponds. One plant consists of a single leaf-like structure with a single tiny root hanging down. Duckweeds can grow and reproduce (asexually) rapidly as each new leaf breaks off and forms a new plant. In this investigation, you will test the influence of environmental factors on the population growth rate of duckweed. You will also estimate the carrying capacity of the environment.

Materials

duckweed plants
plastic cups or 150 mL beakers
pond water
liquid fertilizer (optional)
artificial light source and timer (optional)
water bath or other suitable heat source

Design

With your group, design experiments to test the influence of an environmental variable on the growth rate of a duckweed population and to estimate the carrying capacity of the experimental environment. You may choose from a wide variety of variables such as temperature, nutrient availability, or light intensity. Base your estimate of carrying capacity on the size of population that can be sustained in one container. Be sure to obtain your teacher's approval of your selected variable(s) and experimental design before beginning the experiment.

Note that in order to measure the carrying capacity of the environment directly, the duckweed population must be allowed to grow for an extended period of time. However, it may be possible to generate a crude estimate of carrying capacity by extrapolating graphic data.

Your design must include one or more testable hypotheses; proper selection of independent and dependent variables as well as control(s); a set of procedures and data collection tables; and criteria for analyzing your data, including tracking the changes in population size, density, and growth rate.

Analysis and Evalution

(a) What effect, if any, did the environmental variable have on the growth of the duckweed population?

(b) Was the effect of the variable density-dependent or density-independent? Explain your reasoning.

(c) Describe the growth patterns of your duckweed populations. Did they follow a recognizable or predictable pattern?

(d) Would you describe the duckweed as having an "*r*" or "*K*" reproductive strategy? Explain.

(e) Would you expect your chosen variable to be a limiting factor in natural duckweed populations? Explain your reasoning.

Synthesis

(f) "Environmental factors can eventually limit the maximum size of any growing population." Explain why this statement is undeniable.

(g) No environment is infinite. How did the "cup environment" in your experiment model planet Earth?

(h) If nutrients and light were readily available, the duckweed population in a small container could probably continue to grow until it was limited by physical space. Do you think the same is true of the human population on Earth?
  (i) What do you think is/are the key factor(s) that will eventually limit human population growth?
  (ii) Estimate Earth's carrying capacity for the human population, which is currently more than six billion.
  (iii) Many scientists, economists, and organizations (such as the United Nations) predict that Earth's human population will stop growing late in this century. Conduct research to find out their predictions for the final stable population size.

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EXTENSION

Age Structure Diagrams

Age structure diagrams depict the number of individuals in a population in different age groups. The relative size of age groups can affect the population growth rate. If all other conditions are the same, the population with the highest number of individuals of reproductive age will grow the fastest. This animation shows age structure diagrams for various countries, including Canada.

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Chapter 22 SUMMARY

Outcomes

Knowledge

- describe and explain, quantitatively, factors that influence population growth (22.2)
- describe the growth of populations in terms of the mathematical relationship among carrying capacity, biotic potential, environmental resistance, and the number of individuals in the population (22.1, 22.2)
- explain the different population growth patterns (22.2)
- describe the characteristics and reproductive strategies of *r*-selected and *K*-selected organisms (22.3)

STS

- explain how concepts, models, and theories are often used in interpreting and explaining observations and in predicting future observations (22.2, 22.3)

Skills

- ask questions and plan investigations (22.2, 22.3)
- conduct investigations and gather and record data and information (22.3)
- analyze data and apply mathematical and conceptual models by: designing and performing an experiment or computer simulation to demonstrate the effect of environmental factors on population growth rate (22.2, 22.3)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

22.1

population size
population density
ecological density
population dispersion
clumped dispersion
uniform dispersion
random dispersion

22.2

natality
mortality
immigration
emigration
N
ΔN
growth rate (*gr*)
per capita growth rate (*cgr*)
open population
closed population
exponential growth
r
doubling time (t_d)
environmental resistance
logistic growth
lag phase
log phase
stationary phase
K

22.3

density-dependent factor
intraspecific competition
predation
minimum viable population size
density-independent factor
K-selected organism
r-selected organism

Key Equations

- population density: $D_p = \frac{N}{A}$ or $D_p = \frac{N}{V}$
- population change: $\Delta N = [\text{natality } (n) + \text{immigration } (i)] - [\text{mortality } (m) + \text{emigration } (e)]$
- population growth rate: $gr = \frac{\Delta N}{\Delta t}$
- per capita growth rate: $cgr = \frac{\Delta N}{N}$
- population doubling time: $t_d = \frac{0.69}{cgr}$

MAKE a summary

1. Select a microorganism, plant, or animal and consider its role and functions as an individual and as a part of a population. Describe its life in terms of
   - current population status
   - intraspecific interactions within the population
   - potential changes to population status and size
   - factors that might affect the population growth
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 22
- additional Diploma Exam-style Review Questions
- Illustrated Glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix D5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Most wild populations exhibit
A. random distribution patterns
B. clumped distribution patterns
C. uniform distribution patterns
D. continuously changing distribution patterns

2. Researchers discovered that when populations are large, female arctic ground squirrels run low on food resources and stop reproducing. This is an example of
A. an *r*-selected reproductive strategy
B. a density-dependent factor
C. a change in biotic potential
D. a density-independent factor

3. NR Tree density was determined in a stand of aspen. The tree count was 6400 stems in 3.8 ha. Determine the density of the stand. (Record your answer to two significant digits.)

4. Which statement best describes carrying capacity?
A. the maximum number of individuals of all species that can live in an area
B. the maximum number of individuals of one species that can live in an area
C. the maximum number of individuals of all species that can live continuously and sustainably in an area
D. the maximum number of individuals of one species that can live continuously and sustainably in an area

5. A population of grouse was counted over the years. When graphed, the population size grew rapidly, peaked, and then fluctuated year over year. Which is true of the population?
A. Grouse cannot increase exponentially.
B. The population followed a typical logistic growth pattern.
C. The population appeared to be made up of *r*-selected organisms.
D. The population size fluctuates once it reaches the environment's carrying capacity.

6. Which of the following is *not* a density-dependent factor?
A. predation
B. disease
C. drought
D. intraspecific competition

7. NR A population is growing exponentially at a rate of 14 % per year. How many years will it take for the population to double in size? (Record all two digits of your answer.)

8. A sudden environmental change to a habitat generally favours
A. *K*-selected organisms
B. species that reproduce numerous times in their lives
C. small organisms that are *r*-selected
D. organisms that establish complex symbiotic relationships

9. Which statement is true, if the North American human population is growing at an annual rate of about 0.7 %?
A. The population has effectively stopped growing.
B. The population will soon begin to decline.
C. The population will double in about 100 years.
D. The population will double in about 1000 years.

10. Which of the following represents the correct pattern for a population undergoing logistic growth?
A. lag phase, log phase, stationary phase
B. stationary phase, log phase, lag phase
C. log phase, lag phase, stationary phase
D. lag phase, stationary phase, log phase

11. NR Determine the density of a population of southern flying squirrels, if 940 squirrels were counted in a 68 ha area. (Record your answer to two significant digits.)

Part 2

12. Using two examples, **explain** why it is important for scientists to track the population status of Canadian species.

13. **Identify** and **describe** ways in which the decline of resources in an ecosystem can affect the growth rate of a population in that ecosystem.

Use the following information to answer questions 14 to 18.

Scientists conducted a study into the competition between two species of rodents: the woodland jumping mouse, *Napaeozapus insignis,* and the meadow jumping mouse, *Zapus hudsonius.* The meadow jumping mouse is known to be able to exist in both field and forest habitats. Both species of mice are seed feeders. The experimental design included the selection of three approximately 100 ha plots with similar plant cover. Plot 1 (100 ha) supported a population of *N. insignis,* plot 2 (92 ha) supported a population of *Z. hudsonius,* while plot 3 (104 ha) supported populations of both *N. insignis* and *Z. hudsonius.* The populations of mice were monitored over a period of 4 years (**Table 1**, next page).

Table 1 Experimental Data of Mouse Populations

	Plot 1 (100 ha)	Plot 2 (92 ha)
Mouse species	*N. insignis*	*Z. hudsonius*
year 1	632	345
year 2	788	461
year 3	840	509
year 4	671	328
	Plot 3 (104 ha)	
Mouse species	*N. insignis*	*Z. hudsonius*
year 1	610	102
year 2	559	188
year 3	663	173
year 4	601	80

14. DE **Determine** the average population density for each population in each plot over the four-year study.

15. DE Based on these results, what can you **infer** regarding the interactions between these two rodent species?

16. DE **Identify** the type of interaction occurring in plot 3.

17. DE Some biologists might argue that the evidence from this study is inconclusive due to the assumptions being made by the researchers. **Identify** three such assumptions and criticize the acceptability of each.

18. DE **Describe** the improvements that could be made to the experimental design used in this study.

19. Six ground finches began nesting on an island in 1990. Biologists monitored numbers in this population for nine years, compiling their data as shown in **Table 2**.
(a) **Graphically** show the changes in this population over the nine-year period. Label the various population growth phases on your graph.
(b) **Determine** an estimate of the carrying capacity of the island. Label this value on your graph.

Table 2 Data on Ground Finch Population

Year	Population	Year	Population
1990	18	1995	477
1991	35	1996	359
1992	58	1997	296
1993	170	1998	283
1994	280		

20. **Outline** the elements of the prairie ecosystem that were affected by the depletion of the buffalo herds on the Great Plains of the U.S. and Canada. Consider flora, fauna, and humans as essential elements in your answer.

21. DE **Table 3** shows the population of Alberta from 1901 to 2003. Write a unified response addressing the following aspects of the population changes over this time:
- **Graphically** present the population data for the province of Alberta shown in **Table 3**. Use a spreadsheet program or graphing calculator, if possible.
- **Identify** the decade during which per capita growth rate appears to be greatest. Does this rate of growth appear to be sustainable? **Explain**.
- Use your graph to **determine** an estimate of Alberta's population in 50 years. Do you think this population size will be reached? **Justify** your response.
- During the past 100 years, Alberta's population increased in size by almost 70 times. **Determine** an estimate of the population size if it increased another 70 times in the next 100 years.

Table 3 Population of Alberta

Year	Population (thousands)	Year	Population (thousands)
1901	43	1960	841
1911	247	1965	910
1920	360	1970	1 046
1925	375	1975	1 227
1930	459	1980	2 179
1935	513	1983	2 345
1940	547	1994	2 705
1945	565	1997	2 838
1950	623	2001	2 975
1955	717	2003	3 164

chapter

23 Population Interactions

In this chapter

- Exploration: Effects and Consequences
- Investigation 23.1: Planting Opposition: Intraspecific and Interspecific Competition
- Web Activity: Gause's Principle
- Web Activity: Elk Management in Banff National Park
- Lab Exercise 23.A: Predator–Prey Cycles
- Mini Investigation: Finding a Host
- Web Activity: Zebra Mussels
- Web Activity: Wildfires and Succession
- Investigation 23.2: Microbial Succession
- Career Connection: Interpretive Naturalist

Individual species do not live and evolve in isolation. They are all members of ecological communities, which are made up of many interacting populations within a physical environment that may itself be changing. Just as individual species exhibit recognizable traits that have evolved over long periods of time, entire ecosystems exhibit clearly identifiable patterns and relationships that not only characterize the interactions of living things with their environment, but are also dynamic in time and space.

The relationships between the members of an ecological community are always changing. They may change gradually, as the ecosystem slowly matures, or abruptly, if it is suddenly disrupted by a significant event. Whatever the case, change is inevitable. While very few species can significantly modify their environment, most have adaptations that can help the organism thrive in a changing ecosystem.

Humans, an intelligent and successful species, are unique among all species. Our use of tools has allowed us to live in environments well outside our biological range of tolerances: we inhabit almost every terrestrial ecosystem on Earth (**Figure 1**). Even so, the human species experiences the same limitations as other species do. Like all populations, humans live in finite environments with limited carrying capacities. Today, the rapidly growing human population and its consumption of resources place significant stresses on those environments.

STARTING Points

Answer these questions as best you can with your current knowledge. Then, using the concepts and skills you have learned, you will revise your answers at the end of the chapter.

1. Study the images in **Figure 1 (a)–(c)** and reflect on the following questions:
   (a) What are some factors that enable the human species to live in different environments?
   (b) What are the key resources needed to support any human population? Where and how are these resources obtained?
2. Compare the ways in which urban populations differ from rural populations in how they obtain resources.
3. What are potential ecological effects on the environment of the activities of large human populations?

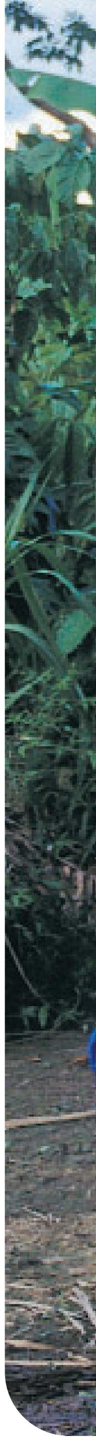

Figure 1
Using our skills to adapt to the environmental conditions, humans now live almost everywhere on Earth.

Exploration — *Effects and Consequences*

With two or three other students, brainstorm some possible effects of the human population on each of the following:

- forests
- grain and livestock production
- wildlife
- water supply and water quality
- biodiversity
- the atmosphere
- harvesting of seafood

(a) Design a concept map to illustrate these effects.

(b) Present your concept map to the class.

23.1 Interactions within Communities

CAREER CONNECTION

Interpretive Naturalist
A career as an interpretive naturalist involves research in natural history and the environment, and also presenting that information to the general public. Most interpretive naturalists work for a park, botanical garden, or wilderness area. This career needs a sound understanding of populations and how they interact in an environment or ecosystem. What kind of training and experience is needed to enter this career?

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Populations do not live in isolation. Within a given ecosystem, populations of different species interact in a community. Within each community, each organism occupies its own ecological niche. Ecologist Eugene Odum describes an organism's ecological niche as its "occupation." For example, on the African savannah, a variety of interactions occur among organisms (**Figure 1**). While the lions, zebras, water buffalo, and antelope all occupy the same habitat, each member of this community uses different mechanisms to survive.

Figure 1
An African grassland community. The African lion's ecological niche includes what it eats, what eats it, the way it reproduces, the temperature range it tolerates, its habitat, its behavioural responses, and any other factors that describe its pattern of living.

Interactions among individuals of different species (interspecific) in a community have important influences on the population dynamics of individual species. Although species interact in various ways, interactions between two species and their effects on the population density can be classified into the five categories shown in **Table 1**. **Symbiosis** includes a variety of interactions in which two species live together in close, usually physical, association. Parasitism, mutualism, and commensalism are types of symbiotic interactions.

symbiosis various interactions in which two species maintain a close, usually physical, association; includes parasitism, mutualism, and commensalism

Table 1 Classification of Interactions between Two Species

Interaction		Effect on populations
interspecific competition		Interaction may be detrimental to one or both species.
predation		Interaction is beneficial to one species and usually lethal to individuals of the other.
symbiosis	• parasitism	Interaction is beneficial to one species and harmful, but not usually fatal, to the other.
	• mutualism	Interaction is beneficial to both species.
	• commensalism	Interaction is beneficial to one species and the other species is unaffected.

Interspecific Competition

Interspecific competition occurs between individuals of different species and restricts population growth. Interspecific competition can occur in two ways. Actual fighting over resources is called **interference competition**. An example of interference competition is the fighting that sometimes occurs between tree swallows and bluebirds over birdhouses. The consumption or use of shared resources is referred to as **exploitative competition**. An example of exploitative competition occurs when both Arctic foxes and snowy owls prey on the same population of Arctic hares.

The strongest competition occurs between populations of species with overlapping niches. The more that niches overlap, the greater the competition between species, as demonstrated by Russian ecologist G.F. Gause. Gause tested the theory that two species with similar requirements could not coexist in the same community. He predicted that one species would consume most of the resources, reproduce efficiently, and drive the other species to extinction. Gause's experiments led to the conclusion that, if resources are limited, no two species can remain in competition for exactly the same niche indefinitely. This became known as Gause's principle, or **competitive exclusion**. In nature, such severe competition is usually avoided by **resource partitioning**, in which different species with similar requirements use resources in different ways—for example at different times or in different places.

The results of interspecific competition take on several forms:

- the population size of the weaker competitor could decline;
- one species could change its behaviour so that it is able to survive using different resources;
- individuals in one population could migrate to another habitat where resources are more plentiful.

In any of these cases, competition would decline.

interspecific competition competition between individuals of different species

interference competition interspecific competition that involves aggression between individuals of different species who fight over the same resource(s)

exploitative competition interspecific competition that involves consumption of shared resources by individuals of different species, where consumption by one species may limit resource availability to other species

competitive exclusion the concept that, if resources are limited, no two species can remain in competition for exactly the same niche indefinitely; also know as Gause's Principle

resource partitioning avoidance of, or reduction in, competition for similar resources by individuals of different species occupying different non-overlapping ecological niches

INVESTIGATION 23.1 *Introduction*

Planting Opposition: Intraspecific and Interspecific Competition

Virtually all naturally occurring organisms are in competition—either with members of their own species (intraspecific competition) or with members of different species (interspecific competition). In this investigation you will design and conduct experiments to measure the effect of both intraspecific and interspecific competition on plant seedlings.

Report Checklist

● Purpose	● Design	● Analysis
○ Problem	● Materials	● Evaluation
● Hypothesis	● Procedure	● Synthesis
● Prediction	● Evidence	

To perform this investigation, turn to page 776.

WEB Activity

Case Study—Gause's Principle

Ecologists describe the struggle for survival in terms of the competitive interactions between different species in nature. Gause was an ecologist who studied the effects of competition on two *Paramecium* species. He grew each species separately in culture tubes, and then put the two together in the same tube. In this Web Activity, you will compare the growth and population densities of the *Paramecium* populations, both separately and together.

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Changes in Population Size of a Predator and Prey

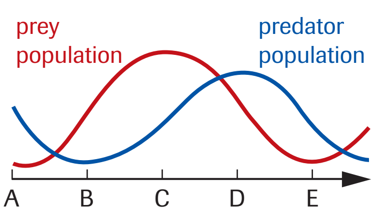

Figure 4
A model of the predator–prey cycle. Because of the oscillations in the populations, the line on this graph is referred to as a sinusoidal curve.

Population Size of Canadian Lynx and Snowshoe Hare

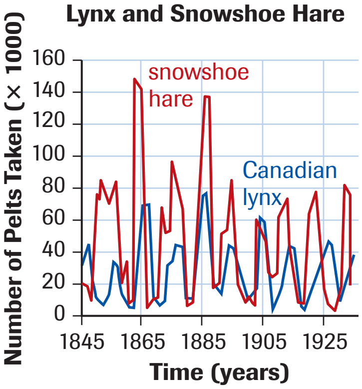

Figure 5
A 10-year cycling pattern in the population of Canadian lynx and the population of snowshoe hare

Predation

Predation is an example of an interspecific interaction in which the population density of one species—the predator—increases while the population density of the other species—the prey—declines. Predator–prey relationships can have significant effects on the size of both predator and prey populations. When the prey population increases, there is more food for predators. This abundance can result in an increase in the size of the predator population. As the predator population increases, however, the prey population decreases. The reduction of prey then results in a decline in the predator population, unless it has access to another food source. There are time lags between each of these responses as the predator population responds to changes in prey abundance.

Some predator–prey relationships coexist at steady levels and display a cyclical pattern. The two species tend to cycle slightly out of synchronization, with the predator patterns lagging behind the prey patterns (**Figure 4**). In this model of a predator–prey cycle, adjustments to population size can be seen during the time intervals from A to E. This graph is referred to as a sinusoidal curve. At time A, when the prey population density is low, the predators have little food and their population declines. A reduction in the predator population allows the prey population to recover and increase. The predator population does not increase again until they begin to reproduce (at time B). Prey and predator populations grow until the increase in the predator population causes the prey population to decline (from time C to time E). As the predator population increases, more of the prey population is devoured. The resulting low density in the prey population leads to starvation and lowered fecundity among predators, slowing its population growth rate (at time D).

In nature, many factors can influence this model of the sinusoidal predator–prey cycle. In 1831, the manager of the Hudson's Bay Company in northern Ontario reported that there was a scarcity of snowshoe hares and the local Ojibwa population was starving as a result. In the early 1900s, wildlife biologists began analyzing the fur-trading records of the Hudson's Bay Company. They discovered that the hares have a population cycle of 10 years. The population cycle of the Canadian lynx, a significant predator of snowshoe hares, mirrors, with a slight time lag, the changes in the snowshoe hare population (**Figure 5**).

WEB Activity

Case Study—Elk Management in Banff National Park

Human activities such as agriculture and over-hunting often disrupt the natural balance of wildlife populations. This can lead to a loss or reduction in the home range of a particular species and an associated decline in its population size. Management programs may lead to a recovery of the species. An interesting case of the influence of humans on wildlife populations is the history of the elk that live in Banff National Park, Alberta.

In this activity, you will consider ecological and human/elk issues around elk in the park. You will also assess preliminary results of the Banff National Park Elk Management Strategy on elk population biology.

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EXTENSION

Natural Selection and Predator/Prey Interactions
Find out about the concept of co-evolution and the role that predator-prey interactions play in the evolution of species.

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LAB EXERCISE 23.A

Predator–Prey Cycles

Report Checklist

○ Purpose	○ Design	● Analysis
○ Problem	○ Materials	● Evaluation
● Hypothesis	○ Procedure	● Synthesis
○ Prediction	○ Evidence	

The large white-tailed deer population in a forest reserve in Alberta has caused concern about overgrazing that might lead to the extinction of plant and animal species found there. To manage this excessive deer population, forest personnel decided to introduce its natural predator, the wolf (**Figure 6**). In the year 1990, 2000 deer lived within the reserve, and 10 wolves were flown into this reserve. Population densities of white-tailed deer and wolves were monitored for a 10-year period.

Problem

What effect does the introduction of a natural predator, the wolf, into a habitat have on the white-tailed deer population?

Hypothesis

(a) Develop a hypothesis about the effect on the white-tailed deer population as a result of the introduction of wolves into their habitat.

Evidence

Table 2 Changes in White-tailed Deer and Wolf Populations

Year	White-tailed deer	Wolves
1990	2000	10
1991	2300	12
1992	2500	16
1993	2360	22
1994	2244	28
1995	2094	24
1996	1968	21
1997	1916	18
1998	1952	19
1999	1972	19

Analysis

(b) Plot the changes in the white-tailed deer and wolf population using the data in **Table 2**, including both sets of data on one graph and using an appropriate labelling method. Use two separate *y*-axes, one on the left-hand side of the graph for deer and the other on the right-hand side for wolves, each with an appropriate scale.

Evaluation

(c) Is wolf predation a limiting factor in this forest reserve? Explain your reasoning.

(d) What other factors might limit the deer population?

(e) Explain how the number of wolves in the reserve is influenced by the size of the deer population.

Figure 6

Synthesis

(f) The Atlantic cod population was an extremely abundant stock of primary economic importance to fishing communities throughout the Atlantic provinces. The Department of Fisheries and Oceans has stated that the collapse in Atlantic cod stocks can be attributed to overfishing. Others claim that the use of equipment that disturbs fish spawning sites on the ocean floor is primarily responsible, and still others argue that the harp seal, a predator of Atlantic cod, is responsible for this mass reduction in the cod population. One suggestion to help cod stocks recover is to kill large numbers of harp seals. Suggest some ways that marine biologists might study changes to the Atlantic cod population to determine whether reducing the harp seal population would be an effective solution.

DID YOU KNOW ?

A Twig or a Caterpillar?

Some prey species use this passive defence mechanism to hide from predators. For example, the inchworm in **Figure 7** is camouflaged, blending in with its surroundings. Camouflage is also called cryptic coloration.

Figure 7

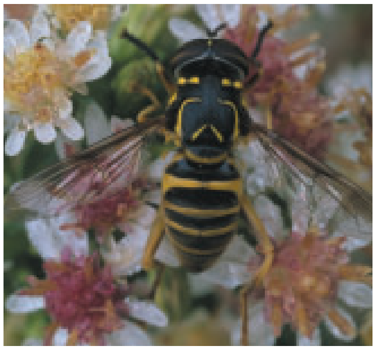

Figure 9

This syrphid fly is less likely to be preyed upon because it mimics stinging bees and wasps.

Defence Mechanisms

Predator–prey interactions have resulted in the evolution of various defence mechanisms in plant and animal species, through repeated encounters with predators over time. Plants use both morphological defences—such as thorns, hooks, spines, and needles—and chemical defences against herbivores. The mustard family of plants, for example, contains oils that give off a pungent odour and make them distasteful and toxic to some insects. Some plants, such as balsam fir, produce chemicals that mimic an insect growth hormone. When a young linden bug (*Pyrrhocoris apterus*) feeds on balsam fir, it remains in the juvenile stage and eventually dies.

Some insects use chemicals produced by their food as a defence against their own potential predators. For instance, the monarch butterfly uses potent plant toxins to make itself distasteful to its predators (**Figure 8**). Caterpillars of the monarch butterfly obtain these toxins by feeding on plants of the milkweed family. The toxins are stored in fatty tissues of the caterpillar, making both it and the adult butterfly unpalatable.

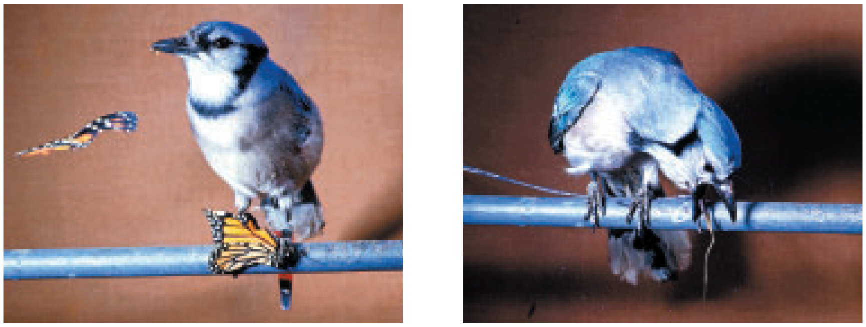

Figure 8

The monarch butterfly and its predator, the blue jay, provide an example of defence mechanisms by prey against predators. Blue jays have been known to regurgitate a monarch butterfly after swallowing it.

Animals sometimes employ passive defence mechanisms, such as hiding, or active defences, such as fleeing from their predators. Active defences are more costly to the prey in terms of energy use than are passive defences. Some species, such as Richardson's ground squirrels, use alarm calls to signal each other when a predator is near. Some animals give a visual warning to predators of their chemical defence mechanisms, such as poisons.

Both predator and prey species can protect themselves through mimicry. In one type of mimicry, a palatable or harmless species mimics an unpalatable or harmful organism, a phenomenon often observed in insects. Predators are often fooled by these mimics who, as a result, avoid predation. A typical example is the harmless syrphid fly that looks remarkably similar to bees and wasps (**Figure 9**).

mutualism a symbiotic relationship in which both organisms benefit; as neither is harmed, it is categorized as a +/+ relationship

commensalism a symbiotic relationship in which one organism benefits and the other organism is unaffected; it is categorized as a +/0 relationship

Symbiosis

Symbiosis, meaning "living together," refers to a relationship in which organisms of two different species live in close, usually physical, contact. At least one of the two species benefits from the association. One type of symbiotic relationship is **mutualism**, which occurs when both species in the relationship benefit and neither is harmed. Most biologists also include as symbiotic relationships **commensalism**, which occurs when one organism benefits and the other neither benefits nor is harmed, and **parasitism**, which occurs when one organism benefits at the expense of another organism's well-being.

Mutualism

There are many common examples of mutualism in which both organisms benefit. Bacteria live in the guts of herbivores, such as cows, deer, and sheep. These animals do not produce the enzymes required to digest plant products such as cellulose and lignin. The bacteria secrete enzymes to break down these products into useable nutrients for the animals. In return, the bacteria are provided with nutrition themselves. Beneficial bacteria also live in the large intestines of humans, producing nutrients such as vitamins B and K, which our cells can use.

Commensalism

It can be difficult to classify a relationship as an example of commensalism. Some biologists argue that they do not exist at all, since it is very difficult to determine whether an individual of the unaffected species is, in fact, benefiting or being harmed. Caribou and Arctic foxes interact in a way that has been classified as commensalistic (**Figure 10**). The foxes follow the caribou herds when they forage for food in their wintering grounds. The caribou have shovel-like feet that can remove snow from lichens on the ground, which is the caribou's primary food source. The caribou expose many small mammals, which are eaten by the foxes. Thus, the foxes benefit from this interspecific interaction and the caribou neither benefit nor are harmed by it. In a similar way, tropical "ant birds" follow army ant colonies through the rainforest, feeding not on the ants but on the other insects and small animals that are disturbed by the ants.

Parasitism

Most parasites live and feed on or in the bodies of other living organisms, and cannot complete their life cycle in the absence of their hosts. Parasitism is extremely common. Biologists estimate that as many as one in four animal species may be parasites. Virtually all species of plants and animals are hosts to one or more species of parasite. While the best-known parasites are responsible for serious human diseases—such as malaria, schistosomiasis, and African sleeping sickness—the vast majority of parasites cause little or no significant harm to their host. This makes sense, since they would be harming the environment on which their own survival relies.

Parasites do not always live on or in another organism. Some species are classified as **social parasites**. These organisms manipulate the behaviour of another species so that they can complete their life cycle. North American cowbirds are social parasites. They lay their eggs in the nests of other smaller birds and, therefore, do not have to expend energy building their own nests or feeding their own young. The cowbird eggs usually hatch earlier and the larger newborn cowbirds monopolize the food resources. The other newborn birds are usually killed, resulting in a very high survival rate for the young cowbirds.

parasitism a symbiotic relationship in which one organism (the parasite) benefits at the expense of another organism (the host), which is often harmed but usually not killed; it is categorized as a +/− relationship

Figure 10
Caribou unknowingly help Arctic foxes by exposing snow-covered habitats of fox prey.

EXTENSION

CBC radioONE QUIRKS & QUARKS

Altruism: Why Can't We All Just Get Along?
Dr. Sigal Balshine, Dr. David Sloan Wilson, Dr. Joel Peck, and Dr. Troy Day, discuss their research into interspecific interactions, particularly altruism and co-operation.

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social parasite a parasite that completes its life cycle by manipulating the social behaviour of its hosts

mini Investigation — *Finding a Host*

Internal parasites live in hosts that eventually die, usually due to something other than the parasite. For this reason it is essential that parasites be able to find and invade new host individuals on a regular basis. This is particularly challenging for internal parasites and results in very complex life cycles for these species.

- Choose an internal parasite and research the ways it is able to get from one host to another. Common internal parasites include flukes, tapeworms, *Plasmodium*, and *Trypanosome* species.

(a) Draw the life cycle of your chosen parasite, indicating how it gets from one host to another.

Figure 11
Some African killer bees escaped from Brazilian beekeeping operations and have spread accidentally into North America.

Disruption of Community Equilibrium

Biological communities are stable when the resources necessary for survival are sustained, populations do not exceed their environment's carrying capacity, and interspecific interactions contribute to biodiversity. Interspecific interactions help to maintain the necessary equilibrium within the complex and dynamic natural systems that sustain communities. A variety of disturbances can affect this equilibrium in drastic ways. A natural disaster can disturb most populations within a community and can break down the intricate interactions among its organisms. The introduction of exotic species can have devastating biological and economic effects on the habitats they invade (**Figure 11**). These nonindigenous species, often with few predators, may reduce or eliminate indigenous species by outcompeting them for food and habitat, or by preying on them. Some recent examples of the harmful effects of introducing an exotic species into an ecological community are shown in **Table 3**.

Table 3 Selected Invading Species

Wild caraway (*Carum carvi*)	Grown in Western Canada as a spice crop, non-native "wild" caraway has escaped cultivation. In parts of Alberta this species is now invading pasture, rangeland, and natural habitats. It is not consumed by livestock and when left uncontrolled can quickly outcompete many other plant species.
African killer bees (Figure 11)	These aggressive bees are hybrids of the domesticated European bee and an African bee that was imported to Brazil by scientists. Large numbers of these bees attack much more readily than the common honeybee does. Aside from public safety, Africanized killer bees have a significant economic impact on commercial beekeepers and food production.
West Nile virus	The West Nile virus, detected in wildlife populations throughout North America, was first identified in the West Nile region of Uganda in 1937. It can be transmitted to humans by three species of mosquitoes: *Culex pipiens* (the common household mosquito), *Aedes vexans* (an indiscriminate feeder), and *A. japonicus*. It is responsible for serious wildlife population losses in many parts of the world. The virus is believed to have been accidentally introduced to North America in an exotic frog species.

WEB Activity

Web Quest—Zebra Mussels

Shipping is one of the most common methods of transporting goods long distances. Massive transportation networks depend on cutting-edge technology to stay organized and accident-free. Unfortunately, the sophisticated technology needed to run shipping companies has not been able to stop the transfer of unwanted guests from one part of the world to another. In this Web Quest, you will look at the impact of one of these stowaway organisms—the zebra mussel. This exotic species has had a huge impact in its new environment, and you are going to explore the effects of this little bivalve.

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EXTENSION

Predator-Prey I
In this Virtual Biology Lab, you will explore the effect of changes in populations of predator and prey on population growth, through a series of activities. You can modify factors such as birth rate, death rate, and the level of predation.

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SUMMARY Interactions within Communities

- Predator–prey interactions are affected by a wide range of factors. Both predators and prey have evolved adaptations that enhance survival.
- Symbiosis may result in mutually beneficial relationships between species.
- Commensalism may result in one species indirectly benefiting another.
- Parasitism is an interaction in which one species feeds and lives in or on a host organism to the detriment of the host.
- Invasions by exotic species, human interference, and natural disasters can disrupt the stability of an ecological community.

EXTENSION

CBC radio ONE QUIRKS & QUARKS

Mosquitoes versus Malaria

Dr. Ken Vernick and his colleagues have discovered that a large proportion of *Anopheles* mosquitoes have a genetic resistance to the malaria parasite. They are able to kill the parasite as soon as it enters their body, so they can't pass the disease on to humans.

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Section 23.1 Questions

1. For each of the following examples, identify what type of interspecific competition is occurring and justify your answer.
   (a) Argentine ants can displace indigenous ants from a community by rapidly depleting resources.
   (b) Some plants release toxins that kill or inhibit the growth of other plants, thereby preventing them from growing in close proximity where they may compete for space, light, water, and food.
   (c) In the Kibale Forest in Uganda, mangabey monkeys, a large species, drive away the smaller blue monkeys.
   (d) Hawks and owls rely on similar prey, but hawks feed during full daylight while owls hunt and feed from dusk to dawn. What term is used to describe this method of avoiding competition?
2. A study was conducted of mussels and the starfish *Pisaster* in the intertidal area along the shore. Results showed that greater diversity of marine invertebrates was found in the area where *Pisaster* and mussels were present together, compared to where mussels were found alone. Explain this observation in terms of competition.
3. Identify the type of defence mechanism in each of the following examples:
   (a) Tiger moths have a highly detailed wing pattern that makes them virtually undetectable against tree bark.
   (b) When attacked by ants, ladybugs secrete a sticky fluid that entangles ant antennae long enough to allow the ladybug to escape.
4. Explain how predation differs from parasitism.
5. Termites eat wood but cannot digest it. They have unicellular, heterotrophic organisms called zoomastigotes living inside their digestive tract that do this for them. Identify the type of interspecific interaction between the termites and the zoomastigotes.
6. In the Great Smoky and Balsam Mountains, ecologists are studying two species of salamander. *Plethodon glutinosus* usually lives at lower elevations than its relative, *P. jordani*, shown in **Figure 12**, although the researchers have found some areas inhabited by both species. As part of the study, the scientists established different test plots from which one of the species was removed and control plots in which the populations remained untouched. After five years, no changes were observed in the control plots, but in the test plots, salamander populations were increasing in size. For instance, if one of the test plots was cleared of *P. jordani*, it had a greater population density of *P. glutinosus* and vice versa. What inferences or conclusions might be drawn from this investigation?

Figure 12
Salamander *Plethodon jordani*

7. Insects are sometimes used as biological control agents, replacing chemical herbicides to control agricultural weeds. For example, in an area near Edmonton, Alberta, the black dot spurge beetle (*Aphthona nigriscutis*) was released in an attempt to control the leafy spurge, an aggressive weed species. The results were dramatic: a 99 % reduction in spurge density and a 30-fold increase in grass biomass after four years. Research some costs and benefits of using insects as biological controls. Summarize your research on the societal, economic, ecological, and environmental impacts in a PMI chart.

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23.2 Succession

Figure 1
New life begins after a devastating forest fire.

Few things appear as devastating as the destruction of a mature forest by a severe fire. All that remains is a blackened landscape with a few solitary tree trunks starkly pointing to the sky. Within a few weeks, however, the ground will slowly turn green as annual and perennial plants, tolerant of the sunlight and the resulting high soil temperatures, begin to grow and reproduce in a soil made fertile by the mineral content of the ash (**Figure 1**). Within two or three years, shrubs and young trees are evident and growing rapidly. A few years later, an untrained observer would probably never know that the area had once been burned out. Over the long term, a forest will become established and reach maturity. When mature, the forest will remain until another disturbance, natural or human-caused, once again alters the abiotic environment and vegetation.

Along with the changing vegetation is a corresponding progression in the variety of animals (birds, mammals, insects) present. Populations enlarge and then decline as the habitat slowly but surely changes.

The pattern described is not limited to forest communities. Other terrestrial regions of the biosphere, such as prairie and tundra, also show regular regrowth following environmental change. This process is referred to as succession. **Succession** describes the gradual changes in the vegetation of an area as it develops toward a final stable community, called a **climax community**.

There are two types of succession. **Primary succession** occurs in an area in which no community existed previously, for example, after a volcanic eruption or when bare rock or mineral soil is exposed by human activity or from beneath a retreating glacier. Lichens and mosses, usually the first to colonize the bare rock surface, release chemicals that help break the rock into fine soil particles. Slowly, by this break-down and weathering, enough soil and dead organic matter accumulate to support small plants. These plants form a community that begins to support a growing diversity of organisms. Over time, the community changes as new species become established and former species are outcompeted. Eventually, a relatively stable plant community forms. **Figure 2** shows a hypothetical process of succession in a forest ecosystem.

Secondary succession occurs when a community is partially or completely destroyed and its dominant plant species have been eliminated. Such destruction may result from causes such as fire, severe flooding, landslides, or human disturbance. Regrowth after a forest fire is the best-known example of secondary succession. Since soil is already present, the lengthy process of soil formation (seen in primary succession) is not necessary. The first plant community to appear, along with its associated animal species, is referred to as the **pioneer community**. Small plants, such as grasses, are common pioneer species. These plants usually have small wind-borne or animal-borne seeds and can exist in full sun and fluctuating soil moisture and temperatures. Moisture levels often dictate which plants survive. As the vegetation develops, however, new ground-level abiotic conditions are set up. As larger plants grow and provide shade, the soil temperature becomes somewhat lower and evaporation is reduced. Decay processes increase the thickness and fertility of the soil layer. Small woody shrubs may then begin to grow, and a new community of plants begins to take over. These plants tend to be taller than the pioneer plants, effectively blocking out much of the solar radiation and contributing even more to the changing microclimate and soil conditions. Often, tree species displace smaller shrubs and form forest communities.

succession the slow, progressive replacement of one community by another during the development of vegetation in any area

climax community the final, relatively stable community reached during successional stages

primary succession the occupation, by plant life, of an area not previously covered by vegetation

secondary succession succession in an area that was previously covered by vegetation and still has some soil

pioneer community the first species to appear during succession

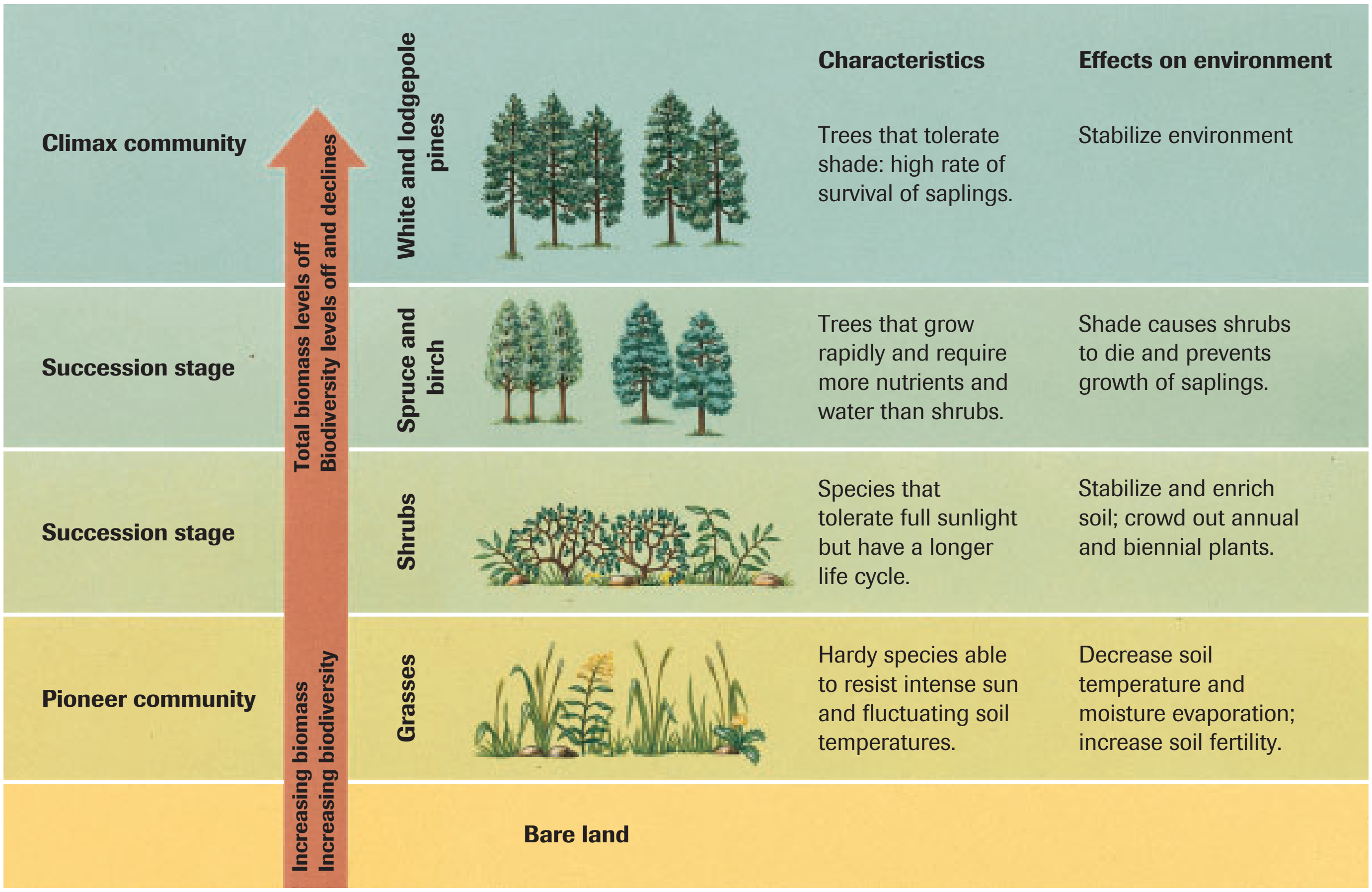

Figure 2
Secondary succession

Just as the plant communities change, so do the ecological niches available to the other species in these communities. As a result, there is a parallel succession of animal, fungal, protist, and bacterial species. Their activities and wastes contribute to the community development. The community continues to change until a final community is reached that can self-perpetuate. This is called the climax community. The process of succession is closely linked to changes in species diversity, net productivity, and biomass. **Figure 3** illustrates the general trends in these factors over 160 years of succession.

While this traditional view of orderly succession provides a good theoretical model of how plant communities change and respond to disturbances, ecologists now recognize that gradual succession, leading directly to a stable climax community, is rare. Instead, successional changes are highly variable and often influenced by frequent and variable disturbances, which can prevent an area from ever reaching a climax community. For example, once they are established, many natural grasslands are maintained by routine fire disturbance—preventing succession to a forest community. Climax communities, if and when established, are in a state of dynamic equilibrium, dominated by the climax vegetation but usually containing extensive areas of vegetation representing earlier stages.

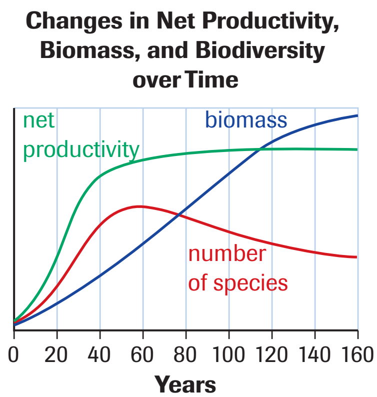

Figure 3
Successional changes in plant communities are accompanied by changes in the net productivity, biomass, and species diversity.

The pattern of succession can also vary between biomes. For example, following a forest fire in a boreal forest biome, the vegetation begins to grow rapidly, as secondary succession commences. The rich vegetation may attract large herbivores, such as deer and moose. However, in a taiga biome, the reverse is possible. Due to the cold climate, lichens, a major food source for the woodland caribou, are extremely slow growing. A fire in these regions may result in a massive decline in the caribou population.

EXTENSION

Succession and *r* and *K* Reproductive Strategies

The dominant organisms at different stages of succession often have different reproductive strategies. This Audio Clip will highlight the different reproductive strategies commonly found in organisms in pioneer communities versus those in climax communities.

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Generalizations about Succession

- Plant succession is triggered by one or both of these factors: disturbances that provide new habitats and removal of previously dominant plant species.
- Succession generally follows a pattern in which smaller pioneer species are replaced by larger species over time.
- Most plant communities exist in a state of flux, with disturbances producing a mosaic of patches in different stages of succession.
- The total number of species increases dramatically during the early stages of succession, begins to level off during the intermediary phases, and usually declines as the climax community becomes established.
- Net productivity generally increases rapidly during the early stages and then levels off.
- Biomass increases during succession and begins to level off during the establishment of the climax community.

WWW WEB Activity

Case Study—Wildfires and Succession

In many terrestrial ecosystems, wildfires play an important ecological role as part of the natural cycle of renewal. Evidence of wildfires can be found in petrified wood dating back nearly 350 million years. A fossilized charcoal, called fusain, is found in the petrified trees once scarred by burning. In this Web-based Case Study, you will evaluate the role of wildfires in two types of ecosystems found in Alberta and elsewhere, forests and grasslands.

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INVESTIGATION 23.2 *Introduction*

Microbial Succession

Ecological succession can describe any set of predictable changes that result in the transition of living communities over time. Successional changes can even occur in environments inhabited almost exclusively by microbes. In this investigation, you will document changes in microbial communities in a hay infusion.

To perform this investigation, turn to page 777.

Report Checklist

Purpose	Design	Analysis
Problem	Materials	Evaluation
Hypothesis	Procedure	Synthesis
Prediction	Evidence	

SUMMARY Succession

- Succession is the series of predictable gradual stages as living communities change over time.
- Primary succession occurs on a barren landscape where no community existed previously.
- Secondary succession occurs after a previous community suffers complete or partial destruction.
- Each stage of succession may be recognized by the presence of one or more characteristic dominant species.

EXTENSION

Wildfires and Succession

You have read about the process of succession. Now, listen to this Audio Clip discussing why non-climax species "sow the seeds of their own destruction." What does this mean for climax species?

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Section 23.2 Questions

1. Distinguish between primary and secondary succession. Which of these processes would you expect to proceed more rapidly? Explain your reasoning.
2. What is meant by a climax community? How would you recognize a climax forest community?
3. Describe three ways in which pioneer plants alter the environment to make it more suitable for later-stage species. Describe two ways in which later-stage species alter the environment to make it less suitable for pioneer species.
4. Name two human activities that can result in secondary succession.
5. Why does succession proceed in a series of stages?
6. Aspen trees produce many extremely lightweight seeds that are carried long distances by the wind. In contrast, oak trees produce relatively small numbers of heavy seeds that fall to the ground and may be carried short distances by foraging animals.
   (a) Which species would you expect to be an early succession species and why?
   (b) What advantage might a large seed give to a plant that must germinate and survive in a late-stage mature forest with heavy shade?
   (c) Would you expect pioneer or late-stage plant species to be more tolerant of dry conditions? Explain.
7. Jack pines produce cones with a waxy outer coating that protects the seeds from extreme heat. After exposure to very high temperatures, the cones open and release their unharmed seeds.
   (a) How does such an adaptation make jack pine a secondary succession specialist?
   (b) How might human forest fire management programs alter the ecology of jack pine forests?
8. Over time, small shallow ponds and bogs can become filled in with sediment and organic matter, eventually becoming forested land. Research the formation of a peat bog and the process of succession in it.
   (a) Describe the mechanisms by which sphagnum moss is able to cover the bog.
   (b) Describe the process by which peat deposits accumulate over time.
   (c) Draw or obtain an image of a cross-sectional view of peat bog formation/succession.

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9. Disturbances occur on many scales. In a forest, small disturbances include the deaths of individual trees that create openings or gaps in the canopy. Large-scale disturbances include forest fires. Modern forestry cutting practices can be used to mimic both of these disturbance scales. Obtain reference materials from the forestry industry and/or a government agency, and use the information you find to answer the following:
   (a) What is a shelter-wood cut? When is this cutting practice chosen and how does it mimic natural disturbances?
   (b) What is a clear-cut? When is this cutting practice chosen, and how does it mimic natural disturbances?
   (c) What are the similarities and differences between these forms of human disturbance and those that they are supposed to mimic in nature?

INVESTIGATION 23.1

Plant Opposition: Intraspecific and Interspecific Competition

Report Checklist

- ● Purpose
- ○ Problem
- ● Hypothesis
- ● Prediction
- ● Design
- ● Materials
- ● Procedure
- ● Evidence
- ● Analysis
- ● Evaluation
- ● Synthesis

Virtually all organisms are in competition, both with members of their own species (intraspecific) and with members of different species (interspecific). Unlike most animals, individual plants cannot move to new locations to avoid or reduce competition; they are constantly in direct competition with their immediate neighbours. Plants compete for a variety of resources, including physical space, soil nutrients, light, and water. In the short term, such competition may result in a reduction in the growth rate or health of individual plants, while in the long term, competition may result in reduced reproductive success or death of some of the plants.

In this investigation you will design and conduct experiments to measure the effect of both intraspecific and interspecific competition on plant seedlings.

Problems

Part 1: Intraspecific Competition

Does the presence of other plants from the same species affect the growth of individual plants?

Part 2: Interspecific Competition

Does the presence of plants from other species affect plant growth differently from the presence of plants from the same species?

Materials

small plant pots
soil mix
plant seeds (variety of species)

Design

Design an investigation and write a detailed procedure to address each problem. Consider coordinating your investigations with those of other groups to maximize the amount of data that you are able to include in your analysis. Groups that share data must use identical experimental designs.

Your design and procedure must include the following:

- clearly stated and testable hypotheses for both your intraspecific and interspecific competition experiments
- independent and dependent variables including a proper control
- careful monitoring of your experiments and gathering and recording of evidence (How will you determine if competition has taken place?)

Once your teacher has approved your design, carry out your procedure. Make sure you follow appropriate safety measures.

Analysis and Evaluation

(a) How did intraspecific competition influence plant growth rates in your trials? Was the effect the same for all species? Suggest explanations to account for any differences.

(b) In your interspecific competition trials, did both plant species suffer from competition equally or did one species appear to "out-compete" the other?

(c) Did you notice any differences between the competing plants and the controls? (For example, did they appear to grow taller?) Did this demonstrate an adaptive response to competition?

(d) Predict the long-term results of both forms of competition if you allowed your plants to continue growing for a year.

(e) The plant seedlings in your experiments may have competed for a variety of environmental resources.

- (i) What do you think were the direct causes of any observed effects? Identify which factor(s) had a role in the competition effects: limited access to light, nutrients, space, or water.
- (ii) Suggest a modification to your experimental design that could be used to test your answer in question (e), part (i), above.

Synthesis

(f) Most plants have obvious adaptations for seed dispersal. Explain how each of the following features enhances seed dispersal.

- (i) the seed head of a dandelion
- (ii) the colourful and tasty fruits of apples and strawberries
- (iii) the hooks on a burr
- (iv) the wing of a pine seed

INVESTIGATION 23.1 *continued*

(g) Do the adaptations in question (f) reduce intraspecific or interspecific competition? Explain.

(h) Most agricultural operations attempt to minimize the influence of competition. Plants that compete with crops are called "weeds" and are often destroyed using herbicide applications or by mechanical removal and cultivation. Conduct research to answer the following:
   (i) What is the most widely used herbicide in Alberta? Approximately how many tonnes are applied each year?
   (ii) List four important weed species in Alberta crops.
   (iii) List the most important advantages and disadvantages of using herbicides to reduce competition with weeds.

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(i) The forestry industry also manages intraspecific and interspecific competition by using a variety of silviculture practices. Conduct research to determine how forestry companies reduce competition from non-commercial plant species and how they manage the competition between individuals of valuable species.

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(j) Allelopathy, the equivalent of underground chemical warfare, is a strategy employed by many plant species to reduce competition. Research allelopathy and report your findings back to the class.

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INVESTIGATION 23.2

Microbial Succession

Report Checklist

- Purpose
- Problem
- Hypothesis
- Prediction
- Design
- Materials
- Procedure
- Evidence
- Analysis
- Evaluation
- Synthesis

Ecological successional changes occur in every inhabited environment on Earth: the surface of a rotting log, the lichens that colonize barren rock, and the development of large coral reefs. Among the least obvious are those that occur in environments inhabited almost exclusively by microbes.

Bacteria and protists fill a variety of ecological niches, including photosynthetic producers, gut symbionts, pathogens, and decomposers. In this investigation you will use a hay infusion to study succession in a microbial community.

Design

In this part of the Investigation, you will design an investigation to observe changes in the microbial populations of a hay infusion. Read the procedure for preparing the hay infusion. Then, generate a hypothesis concerning the relationship between factors such as rates of population growth, types of microorganisms, changes in microbe diversity over time, etc. Your design must enable you to judge the validity of your initial hypothesis.

- How can you test your hypothesis regarding population growth of microbes in the hay infusion?

Write a procedure that will allow you to test your hypothesis. Your procedure must include steps in which you monitor and record the changes that take place in the microbial community over a period of two to three weeks.

- How will you obtain samples of the infusion? Should you sample from different depths in the beaker?
- What equipment and references will you need in order to observe and identify different micro-organisms?
- What safety measures must be observed?
- Will you attempt to quantify the populations of each species, and if so, how?
- How will you record the evidence?

Write a prediction for your experiment.

Materials

2 beakers (250 mL)
water
scissors
hay
hotplate
stirring rod
sieve
distilled water
watch glass or Petri dish lid (to cover one beaker)

Procedure

1. Loosely fill a 250 mL beaker with coarsely chopped hay. Fill the beaker to the 200 mL mark with water.
2. Bring the hay and water to a boil, stirring occasionally, and allow to simmer for 10 minutes.
3. Let the mixture cool overnight.
4. Using the sieve and the second beaker, separate the yellowish infusion from the cooked hay. Discard the hay. Top up the infusion to 200 mL using distilled water.
5. Cut some fresh dry hay into tiny pieces, less than 5 mm in length. Add about 10 mL of this cut hay to your infusion.
6. Cover the beaker with a watch glass or the lid from a Petri dish.
7. Add distilled water as needed to replace water lost due to evaporation.

Analysis

(a) Which types of microbes, bacteria or protists, grew first in the infusion? Suggest an explanation for this observation.

(b) What was the source of the organisms in the infusion? From where did these species originate?

(c) How might a microbe's ability to form resistant spores or cysts enhance its biological success?

(d) How might the order of appearance of the microbes be related to their place in a food chain?

(e) Was there any evidence of photosynthesizing organisms?

(f) Even if no producers are present, an infusion will support a large community of micro-organisms. What is the primary energy source supporting the food chain in such a system?

Evaluation

(g) Modify your procedure so that you could observe microbial succession in an environment that
 (i) had a higher concentration of oxygen gas,
 (ii) had a higher (or lower) pH, and
 (iii) modelled the internal gut environment of a mammal.

Chapter 23 SUMMARY

Outcomes

Knowledge

- describe the basis of species interactions and symbiotic relationships and their influences on population changes (23.1)
- explain the role of defence mechanisms in predation and competition as caused by genetic variation (23.1)
- explain how mixtures of populations that define communities may change over time or remain as a climax community, i.e., primary succession, secondary succession (23.2)

STS

- explain why Canadian society supports scientific research and technological development that helps achieve a sustainable society, economy and environment (23.1)

Skills

- ask questions about observed relationships, and plan investigations (all)
- conduct investigations and gather and record data and information by designing and performing: an experiment or simulation to demonstrate interspecific and intraspecific competition (23.1); an experiment to demonstate succession in a microenvironment and recording its pattern of succession over time (23.2); and by performing simulations to investigate relationships between predators and their prey (23.1)
- analyze data and apply mathematical and conceptual models by summarizing and evaluating a symbiotic relationship (23.1)
- work as members of a team and apply the skills and conventions of science (all)

Key Terms

23.1

symbiosis
interspecific competition
interference competition
exploitative competition
resource partitioning
mutualism
commensalism
parasitism
social parasite

23.2

succession
climax community
primary succession
secondary succession
pioneer community

MAKE a summary

1. Relationships between populations in a community can harm, benefit, or have little or no effect on each population. For each pair, summarize how each species influences the actions of the other. Consider the impact on the entire population as well as on individual members.
   (a) lynx and snowshoe hare
   (b) pioneer plant species and later-stage plant species
   (c) internal parasites and their host species
   (d) Arctic fox and caribou
   (e) honey bees and flowering plants
   (f) monarch and viceroy butterflies
   (g) *Parmecium aurelia* and *Paramecium caudatum*
   (h) an invasive species and a native species sharing similar ecological niches
2. Revisit your answers to the Starting Points questions at the start of the chapter. Would you answer the questions differently now? Why?

Go To

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The following components are available on the Nelson Web site. Follow the links for *Nelson Biology Alberta 20–30*.

- an interactive Self Quiz for Chapter 23
- additional Diploma Exam-style Review Questions
- Illustrated glossary
- additional IB-related material

There is more information on the Web site wherever you see the Go icon in the chapter.

EXTENSION

Issues and Impacts—Fire Ants in the Pants
Fire ants are an imported species that are out-competing native ant species in the southern United States. What strategies are being used to re-establish a more natural balance?

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UNIT 30 D PERFORMANCE TASK

Changes in Human Population Size

The human population can be analyzed in the same way as the population of any other organism, using the tools and knowledge you acquired in this unit. In this Performance Task, you will work in a group to decide if you support or refute this statement: "The human population is growing at an alarming rate and is rapidly approaching Earth's carrying capacity."

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. Which of the following best describes a commensal relationship?
   A. One species benefits and the other is usually killed.
   B. One species feeds on a host species but the host is usually not seriously harmed.
   C. One species benefits and the other is usually unaffected.
   D. Both species benefit.

2. According to the concept of competitive exclusion
   A. no two species can successfully occupy the same habitat at the same time
   B. two members of the same species cannot share the same territory
   C. no two species can successfully occupy the same ecological niche in the same region
   D. using the same resources often leads to the establishment of a mutualistic relationship

3. Which of the following best describes predator–prey relationships?
   A. Predators out-number prey and their population growth lags behind that of their prey.
   B. Prey out-number predators and their population growth lags behind that of the predators.
   C. Predators out-number prey and their population growth precedes that of their prey.
   D. Prey out-number predators and their population growth precedes that of the predators.

4. NR Place the following successional events in the proper sequence. (Record all four digits of your answer.)
   1. Shade-tolerant species begin to become established.
   2. Taller, shade-intolerant species become dominant.
   3. Species that are resistant to high temperatures and dry conditions are abundant.
   4. A community of plants exhibits little change over long periods of time.

Part 2

5. For each of the photographs in **Figure 1**, **identify** the defence mechanism used by each species.

(a) (b) (c) (d)

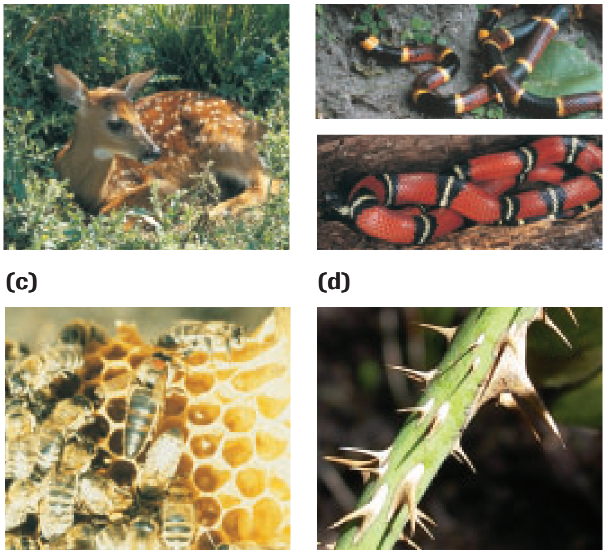

Figure 1
(a) white-tailed deer fawn
(b) venomous Eastern coral snake (top) and harmless Sinoloan milk snake (bottom)
(c) African killer bees
(d) rose

6. In one type of mimicry, several unrelated animal species, all of whom are poisonous or dangerous, resemble one another. For example, monarch and viceroy butterflies have evolved similar coloration (**Figure 2**). **Predict** how this similarity might affect bird species that prey on insects.

(a) (b)

Figure 2
(a) a monarch butterfly
(b) a viceroy butterfly

7. **Explain** why it would be a mistake to eliminate a major predator from a community.

8. **Compare** predators and parasites.

9. DE In an Arctic ecosystem, a fox population begins to prey on small herbivores, such as mice and hares. Caribou are large herbivores that compete for many of the same plants as smaller herbivores. In a unified response, address the following aspects of the changes in this ecosystem:
- **Predict** how the foxes' predation of herbivores will affect the population of plants.
- **Explain** the role of carrying capacity on the size of the population of plants.
- **Predict** how the caribou population will change.

Use the following information to answer questions 10 to 12.

Human activity over the past century extirpated wolves from northern Montana. Coyotes were occupying the habitat as the largest member of the canid family. As a growing wolf population from Alberta invaded the coyotes' territory, Canadian researchers documented the changes in coyote behaviour (**Table 1**).

Table 1 Coyote Behaviour

Before recolonization by wolves
• Coyotes usually were found alone or in pairs.
• Coyotes fed on rabbits, hares, and some plants.
• Coyotes were most active during the early morning and late evening.
• The coyote population was relatively large.
After recolonization by wolves
• Coyotes tended to be found in pairs or small packs.
• Coyotes relied on larger prey and scavenged wolf kills.
• Coyotes avoided times when wolves were active during the winter months.
• Coyotes maintained historic activity patterns during the summer months.
• Coyote population decreased significantly but remained stable.

10. **Describe** the evidence that suggests that the niches of wolves and coyotes overlap.

11. Wolves are known as predators of coyotes. **Identify** the behavioural changes by the coyotes that are likely to reduce the number taken by wolves.

12 Wolves have a dramatically smaller home range in summer when they stay closer to their dens. Does the coyote behaviour seem to account for this change? **Explain**.

Use the following information to answer questions 13 and 14.

The cowbird, a social parasite, lays its eggs in the nests of other birds. The relationship between cowbirds and large grazing mammals is also an example of commensalism. The cowbirds follow migrating herds of mammals, feeding on insects disturbed by the movement of the mammals as they graze. Historically, adult cowbirds were associated with herds of plains bison.

13. **Predict** how the behaviour of cowbirds might have evolved differently if the herds of bison remained in the same small area for weeks at a time during the cowbirds' breeding season.

14. Cowbirds are an open-field species and rarely parasitize nests that are located deep in wooded areas. **Predict** how large-scale clear-cutting of forests might influence the success of this species.

15. Research the sea lamprey, a non-indigenous species, which has had a great impact on the fish communities of the Great Lakes, and then answer the following questions based on your finding:

(a) **Describe** the fundamental and realized niche of the sea lamprey.

(b) **Describe** how sea lampreys may have entered the Great Lake ecosystem.

(c) **Identify** the interspecific interactions of the sea lamprey and its effects on the Great Lakes.

(d) **Describe** some economic setbacks faced by Canadian fisheries as a result of sea lamprey invasion and outline any control efforts.

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16. In 1883, a massive volcanic eruption obliterated half of the island of Krakatau and covered the remainder in ash and pumice, 30 m thick. All previous life was wiped out. Conduct research to learn about the re-colonization of this island by plants and animals.

(a) **Identify** the length of time it took for plants and animals to become re-established on the island.

(b) **Explain** whether the process of succession was rapid or slow.

(c) Do you think the presence of a thick ash layer enhances or inhibits the rate of primary succession? **Explain**.

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Many of these questions are in the style of the Diploma Exam. You will find guidance for writing Diploma Exams in Appendix A5. Science Directing Words used in Diploma Exams are in bold type. Exam study tips and test-taking suggestions are on the Nelson Web site.

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DO NOT WRITE IN THIS TEXTBOOK.

Part 1

1. The bottleneck effect
- A. increases genetic variability thus leading to evolutionary change
- B. results in lower genetic variation within the population resulting in lower viability
- C. refers to the movement of a small number of individuals into a new environment
- D. is an example of evolutionary change due to natural selection

2. Which of the following choices gives three types of symbiotic relationships?
- A. predator–prey, parasitism, commensalism
- B. mutualism, parasitism, commensalism
- C. predator-prey, mutualism, commensalism
- D. parasitism, mutualism, predator–prey

3. It was observed that as the number of night-time flying insects increases in a region, the population of insect-eating bats also increases. This is an example of
- A. density-dependent, intraspecific competition
- B. density-independent, intraspecific competition
- C. density-dependent, predator–prey relationship
- D. density-independent, predator–prey relationship

4. Which of the following is *not* a defence mechanism?
- A. camouflage
- B. leaf toxins
- C. interference competition
- D. mimicry

5. What is the change in population size if natality = 22, immigration = 6, emigration = 7, and mortality = 14?
- A. 7
- B. 9
- C. –5
- D. 23

6. It was estimated that an original population of 74 bull trout in a section of stream increased in number to 110 over three years. The annual population growth rate and per capita growth rate were
- A. 36 and 3
- B. 12 and 3
- C. 36 and 0.49
- D. 12 and 0.49

(Note that units are intentionally omitted.)

7. NR In each of the following, a change in the ecosystems affects the size of a population in the ecosystem:
1. Fertilizer run-off causes an increase in the algae population in a freshwater lake.
2. The introduction of a predator causes a decline in a population size of snow geese.
3. A fatal infectious disease spreads through a poultry farm and causes a decline in the number of chickens.
4. Habitat loss due to urban expansion causes a decline in the population size of grizzlies.

Identify the statements which describe change due to a density-independent factor. (Record all three digits of your answer.)

8. NR Place the following plants in proper sequence from earliest to latest in primary succession. (Record all four digits of your answer.)
1. lichens
2. shrubs
3. trees
4. grasses

9. NR Match the description with the term. (Record all four digits of your answer in the order of the descriptions.)

___ A small population is isolated on an island.
___ Bacteria are observed to become increasingly resistant to antibiotics.
___ Individuals from one population join another.
___ A new trait appears in the population.

1. mutation
2. sexual selection
3. founder effect
4. migration

10. Which of the following is *not* true regarding succession?
- A. Primary succession usually begins on bare rock or volcanic ash.
- B. Secondary succession is the second stage that follows primary succession species.
- C. Many climax species are shade-tolerant.
- D. Fires are a primary cause of secondary succession.

11. Which of the following are all characteristics of primary successional species?
- A. moisture-loving, sun-loving, long-lived
- B. moisture-loving, shade-loving, long-lived
- C. drought-resistant, shade-loving, long- lived
- D. drought-resistant, sun-loving, short-lived

12. NR A forest fire removes all vegetation from an area. Place the following species in the order in which you would expect them to appear during succession. (Record all four digits of your answer.)
1. slow-growing pine trees
2. grasses
3. fast-growing spruce trees
4. shrubs

Part 2

13. **Define** *evolution* in terms of gene frequencies.

14. **Outline** in a list the conditions that must be met to maintain Hardy–Weinberg equilibrium.

15. DE Genetic changes resulting from mutation can be harmful, beneficial, or neutral. Write a unified response that addresses the following aspects of the relationship between mutations and changes in the gene pool of a population.
- **Explain** how harmful mutations have little or no influence on the gene pool of a population.
- **Describe** how beneficial mutations, though more rare, can cause dramatic long-term changes on the gene pool.

Use this information to answer questions 16 and 17.

A recessive allele (*l*) codes for lactose intolerance in humans. As they get older, people who are lactose intolerant lose the ability to digest the lactose sugar in milk. Homozygous dominant (*LL*) and heterozygous individuals (*Ll*) do not have this problem. In Australians of European descent, the incidence of lactose intolerance is only 4 % while 85 % of Australian Aborigines are lactose intolerant.

16. **Determine** the *L* and *l* allele frequencies for these two groups of people.

17. Europeans have a long history of drinking milk from domesticated animals while Aboriginal peoples do not. **How** might this explain such a marked difference in these frequencies? **Relate** your answer to the assumptions required to maintain Hardy–Weinberg equilibrium.

18. Students sampled aquatic insect larvae living on a small section of river bottom measuring 2.0 m by 0.8 m. They found approximately 45 000 black fly larvae in the sample.
(a) **Determine** the population density of this species.
(b) **Determine** an estimate of the number of black fly larvae living in a similar habitat of river bottom measuring 50 m by 10 m.

19. According to the 2001 census, the population of Canada had reached 30 007 094 people.
(a) **Determine** the population density of Canadians, if Canada's land area is 9 976 000 km^2.
(b) Using our population as an example, **explain** why the ecological density of a species is usually greater than its crude density.

20. **Outline** in a list five environmental resources for which there might be intraspecific competition. **Illustrate** each with an example.

21. DE Natality, mortality, immigration, and emigration are all terms that may apply to any population. Write a unified response addressing the following aspects of these processes:
- **Describe** briefly what each term means.
- **Explain** briefly how each process affects a population.
- **Identify** which of the terms do *not* relate to a closed population. **Explain** why not.
- **Outline** in a list several examples of closed populations that occur naturally. **Outline** in a second list examples of closed populations produced by human intervention or other activities.

22. DE **Describe** the changes in population size that give rise to the zig-zag pattern visible in **Figure 1**. Explain why this population growth pattern is so common.

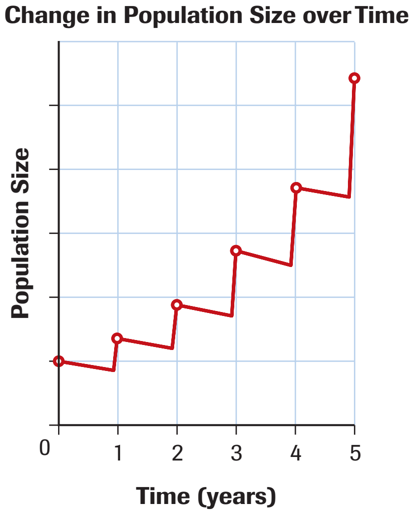


Figure 1

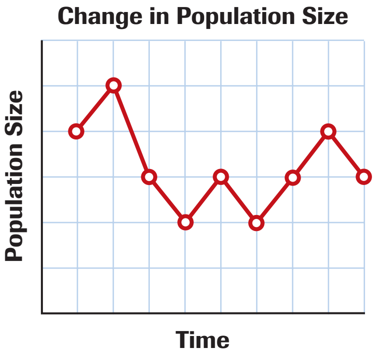
23. **Explain** why small populations often experience relatively slow growth for several generations. **Identify** the name given to this region of slow growth on a sigmoidal curve.

24. **Identify** the conditions that are necessary for a population to experience prolonged exponential growth.

25. **Explain** what happens once a population reaches a dynamic equilibrium.

26. Study the graphs of two different populations in **Figure 2**, on the next page. One graph shows a population of bacteria growing in a laboratory, and the other graph shows a population of owls living in a forest. **Identify** which graph represents which population. **Explain** your reasoning.

(a)



(b)

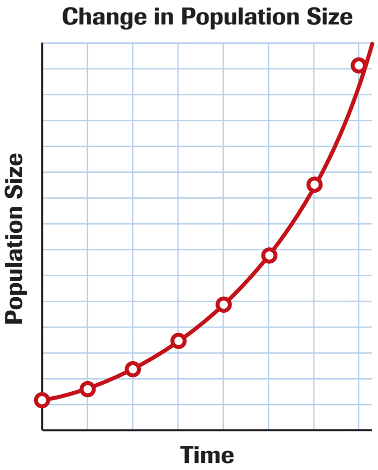


Figure 2

27. **Explain** and **illustrate** with an example the differences between intraspecific and interspecific interactions.

28. **Describe** the obvious defence mechanism utilized by the sea urchin, *Stronglyocentrotus franciacanus*, shown in **Figure 3**. **Infer** the possible adaptive benefit(s) of its bright coloration.

Figure 3
Sea urchin

29. **Describe** and **illustrate** with two examples, each of the following:
(a) commensalism
(b) mutualism
(c) parasitism

30. In a laboratory, researchers placed a *Paramecium* species in a test tube with its predator protozoan. After time, predator–prey cycles became shortened and the system collapsed. The researchers now plan to repeat the experiment with new *Paramecium* being added to the test tube every few days. Write a unified response that addresses the following aspects of the interactions between these two species.
- **Sketch** a graph that shows the changes in the predator and prey populations in the first experiment. Explain the shape of the curves on your graph.
- **Why** did the system collapse in the first experiment?
- **Predict** what the predator-prey cycle will be like in the second experiment. Provide reasoning for your answer. **Justify** your response.

Use the following information to answer questions 31 to 33.

Meadow voles, sometimes referred to as field mice, are extremely common small rodents that breed actively throughout the year with females becoming fertile at under two months of age. The data in **Table 1** represent the growth over time of a population of these voles living in a small grassland.

Table 1 Monthly Growth for a Population of Meadow Voles (Field Mice)

Month	Meadow vole population
December	3 920
January	5 488
February	7 683
March	10 756
April	15 058
May	21 081
June	29 513
July	41 318
August	57 845
September	80 983
October	113 376

31. DE Represent the data **graphically**.

32. DE Based on your graph, **infer** whether the meadow vole population is exhibiting logistic or exponential growth. **Explain**.

33. DE Using your graph, **determine** an estimate of the size of the vole population after three more months.

34. DE **Table 2** compares Canadian population statistics for the periods 1861–1871 and 1991–1996. In 2004, the number of immigrants was about 236 000 while the number of emigrants was approximately 61 000. Write a unified response that addresses the following aspects of these data.
- **Determine** Canada's annual per capita birth and death rates between 1861 and 1871.
- **How** did these values change over the next 120 years? **Hypothesize** reasons for these changes.
- **Determine** the annual per capita growth rate for these two time intervals.
- **Conclude** whether the 2004 values follow the trend(s) in the previous values.

Table 2 Canadian Population Statistics

	1861–1871	1991–1996
starting population	3 229 000	27 852 000
births	1 370 000	1 936 000
deaths	760 000	1 024 000
immigrants	260 000	1 137 000
emigrants	410 000	229 000

35. DE Over the past few hundred years, humans have developed technologies that enable us to drastically alter Earth's environment and influence its carrying capacity for our species. Recently, humans have even placed rovers on the surface of Mars. The rovers have gathered extensive data on the physical characteristics of the "red planet." Data from these and other sources are compared with similar data from Earth in **Table 3**. Write a unified response that addresses the following aspects of the environments of Earth and Mars.
- **Compare** the abiotic features of the two planets that influence their carrying capacity for human life.
- **Identify** the factors that will have to be altered in order to increase the carrying capacity of the planet, if humans are ever to inhabit Mars.
- **Outline** in a list the aspects of our own planet's abiotic and biotic features that we have altered to increase the short-term carrying capacity for the human population.
- **Describe** the impacts that humans are having on Earth that may be decreasing the long-term carrying capacity of Earth.
- Do you think that Mars could support as many humans as Earth in the future? **Justify** your answer.

Use the following information to answer questions 36 to 39.

Researchers recorded the number of individuals in two populations over 8 years. Their data are shown in **Table 4**.

Table 4 Changes in Size of Population A and B

Time (years)	0	1	2	3	4	5	6	7	8
Size of population A	40	60	85	120	170	235	340	330	70
Size of population B	20	25	30	50	115	160	145	155	150

36. DE **Sketch** a graph of the two sets of population data in **Table 4**. on Include the data for both populations on the same set of axes.

37. DE **Identify** which population shows a J-shaped growth curve, and whether its growth pattern is logistic or exponential.

38. DE Between years 5 and 8, both populations show quite different growth patterns. **Explain** the role of the environment in causing these changes.

39. DE **Identify** the species that has a growth curve similar to that of a *K*-selected species. Add a labelled horizontal line to indicate **graphically** the approximate carrying capacity of environment for that species.

40. Review the focusing questions on page 710. Using the knowledge you have gained from this unit, briefly **outline** a response to each of these questions.

Table 3 Abiotic and Biotic Factors on Earth and Mars

	Earth	Mars
atmosphere	thick, 78 % nitrogen gas, 21 % oxygen gas	less than 1 % as dense as that of Earth > 95 % carbon dioxide gas, 0.15 % oxygen gas
weather	highly variable, precipitation in the form of rain and snow	no precipitation, dust storms common
cosmic radiation	mostly shielded by magnetic field	bombardment strong due to weak magnetic field
temperature	highly variable, ranges from extremes of –50 °C to +50 °C	generally very cold with an average of –55 °C.
water	covers over 50 % of Earth's surface; extensive ice caps and cloud cover	present but frozen below the surface, none in liquid form.
life	estimates of 10–30 million species including humans	no known life; microbes remain a possibility
hours/day, days/year	24 h, 365 d	24.5 h, 670 d