

LECTURE PRESENTATIONS

For CAMPBELL BIOLOGY, NINTH EDITION

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Chapter 53

Population Ecology



Lectures by
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Overview: Counting Sheep

- A small population of Soay sheep were introduced to Hirta Island in 1932
- They provide an ideal opportunity to study changes in population size on an isolated island with abundant food and no predators

Figure 53.1



- **Population ecology** is the study of populations in relation to their environment, including environmental influences on density and distribution, age structure, and population size

Concept 53.1: Dynamic biological processes influence population density, dispersion, and demographics

- A **population** is a group of individuals of a single species living in the same general area
- Populations are described by their boundaries and size

Density and Dispersion

- **Density** is the number of individuals per unit area or volume
- **Dispersion** is the pattern of spacing among individuals within the boundaries of the population

Density: A Dynamic Perspective

- In most cases, it is impractical or impossible to count all individuals in a population
- Sampling techniques can be used to estimate densities and total population sizes
- Population size can be estimated by either extrapolation from small samples, an index of population size (e.g., number of nests), or the **mark-recapture method**

- **Mark-recapture method**

- Scientists capture, tag, and release a random sample of individuals (s) in a population
- Marked individuals are given time to mix back into the population
- Scientists capture a second sample of individuals (n), and note how many of them are marked (x)
- Population size (N) is estimated by

$$N = \frac{sn}{x}$$

APPLICATION



Hector's dolphins

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- Density is the result of an interplay between processes that add individuals to a population and those that remove individuals
- **Immigration** is the influx of new individuals from other areas
- **Emigration** is the movement of individuals out of a population

Figure 53.3

Births



**Births and immigration
add individuals to
a population.**



Immigration

Deaths



**Deaths and emigration
remove individuals
from a population.**

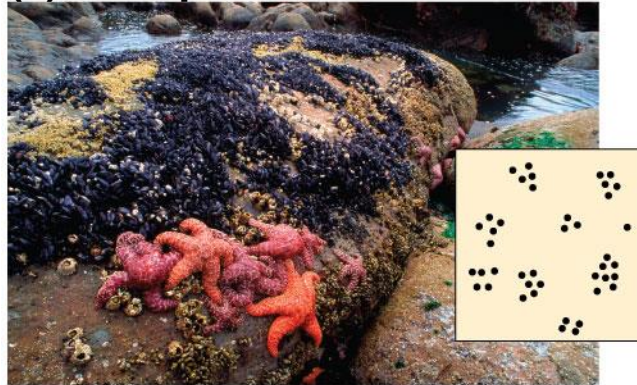


Emigration

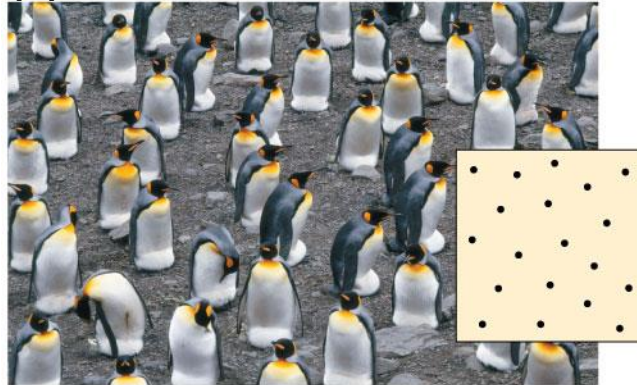
Patterns of Dispersion

- Environmental and social factors influence the spacing of individuals in a population
- In a clumped dispersion, individuals aggregate in patches
- A clumped dispersion may be influenced by resource availability and behavior

(a) Clumped



(b) Uniform



(c) Random



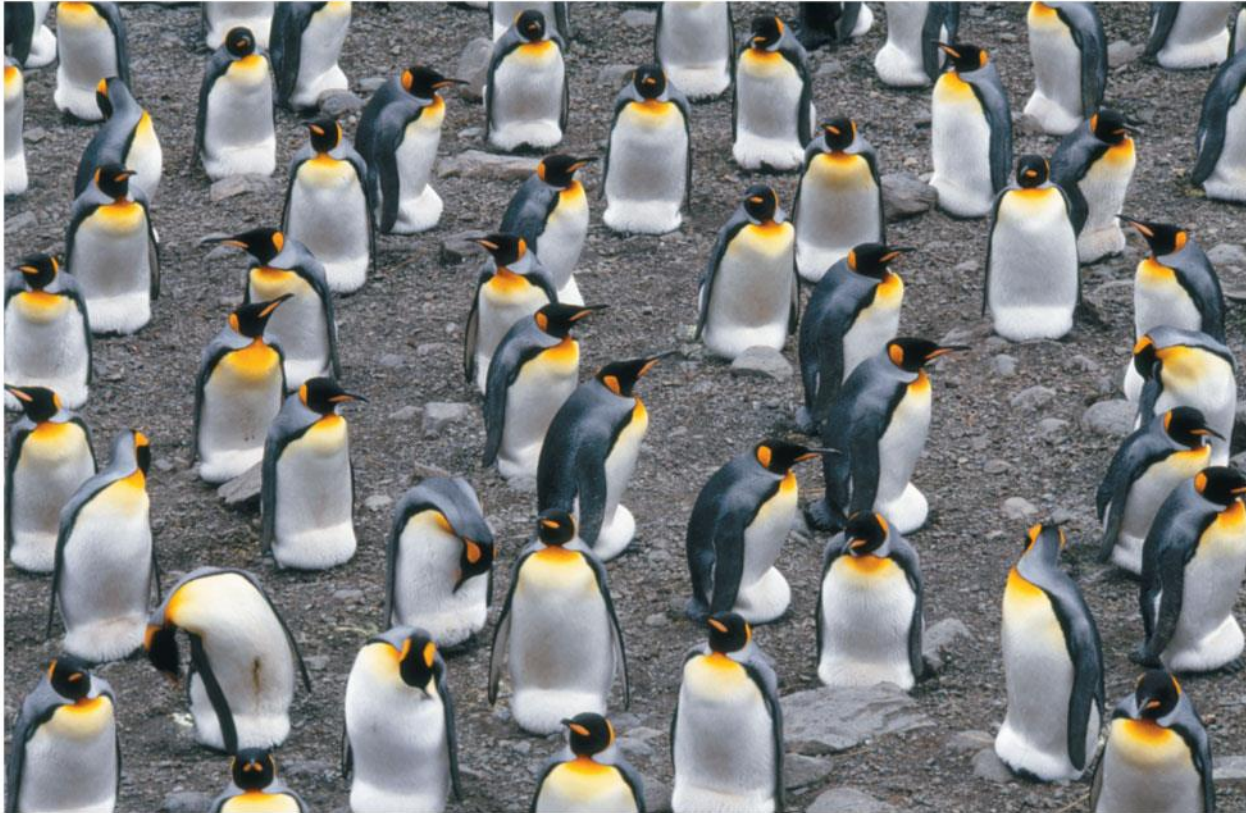
Figure 53.4a

(a) Clumped



- A uniform dispersion is one in which individuals are evenly distributed
- It may be influenced by social interactions such as **territoriality**, the defense of a bounded space against other individuals

(b) Uniform



- In a random dispersion, the position of each individual is independent of other individuals
- It occurs in the absence of strong attractions or repulsions

(c) Random



Demographics

- **Demography** is the study of the vital statistics of a population and how they change over time
- Death rates and birth rates are of particular interest to demographers

Life Tables

- A **life table** is an age-specific summary of the survival pattern of a population
- It is best made by following the fate of a **cohort**, a group of individuals of the same age
- The life table of Belding's ground squirrels reveals many things about this population
 - For example, it provides data on the proportions of males and females alive at each age

Table 53.1

Table 53.1 Life Table for Belding's Ground Squirrels (*Spermophilus beldingi*) at Tioga Pass, in the Sierra Nevada of California*

Age (years)	FEMALES					MALES				
	Number Alive at Start of Year	Proportion Alive at Start of Year	Number of Deaths During Year	Death Rate [†]	Average Additional Life Expectancy (years)	Number Alive at Start of Year	Proportion Alive at Start of Year	Number of Deaths During Year	Death Rate [†]	Average Additional Life Expectancy (years)
0–1	337	1.000	207	0.61	1.33	349	1.000	227	0.65	1.07
1–2	252 [‡]	0.386	125	0.50	1.56	248 [‡]	0.350	140	0.56	1.12
2–3	127	0.197	60	0.47	1.60	108	0.152	74	0.69	0.93
3–4	67	0.106	32	0.48	1.59	34	0.048	23	0.68	0.89
4–5	35	0.054	16	0.46	1.59	11	0.015	9	0.82	0.68
5–6	19	0.029	10	0.53	1.50	2	0.003	2	1.00	0.50
6–7	9	0.014	4	0.44	1.61	0				
7–8	5	0.008	1	0.20	1.50					
8–9	4	0.006	3	0.75	0.75					
9–10	1	0.002	1	1.00	0.50					

Source: P. W. Sherman and M. L. Morton, Demography of Belding's ground squirrel, *Ecology* 65:1617–1628 (1984).

*Females and males have different mortality schedules, so they are tallied separately.

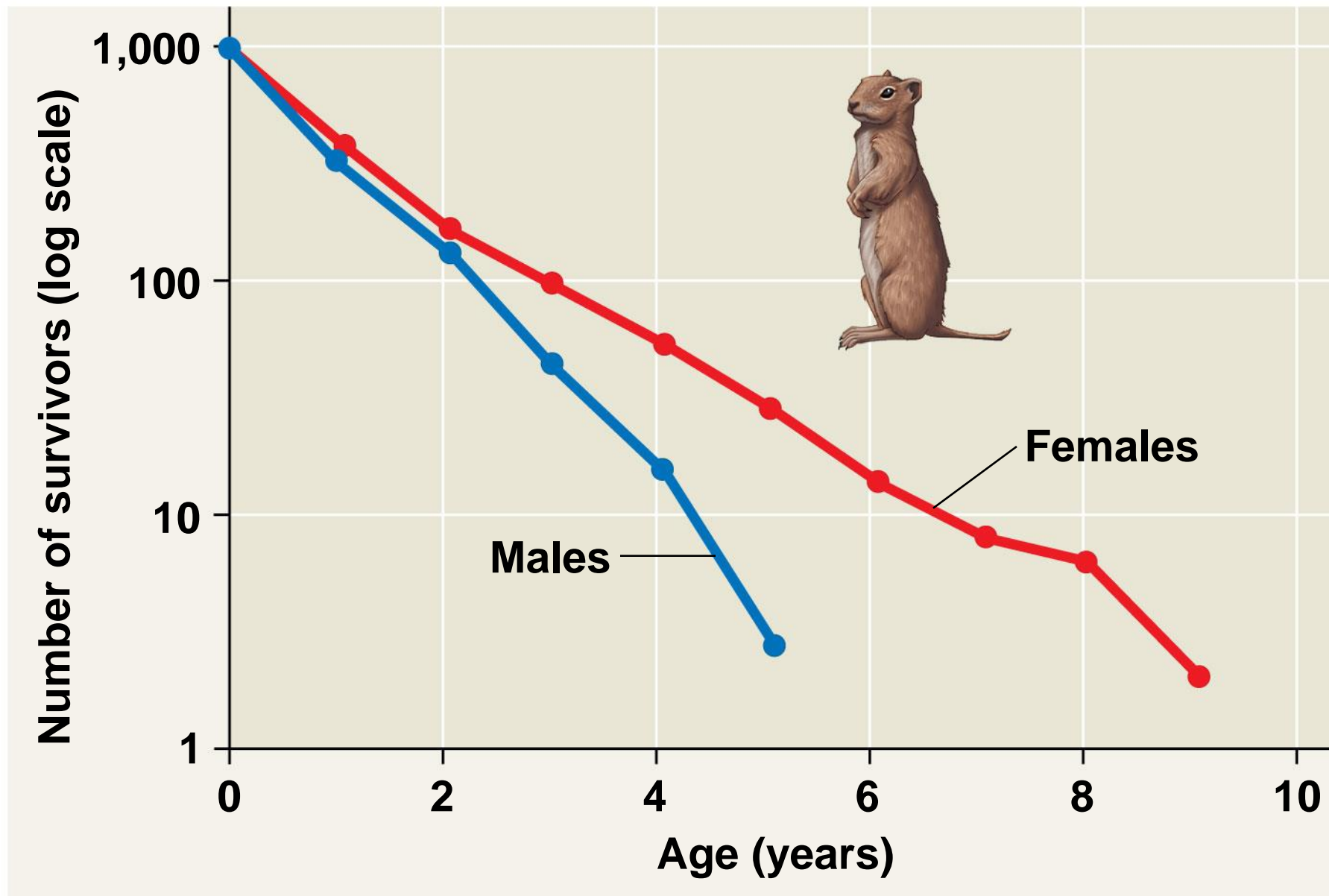
[†]The death rate is the proportion of individuals dying during the specific time interval.

[‡]Includes 122 females and 126 males first captured as 1-year-olds and therefore not included in the count of squirrels age 0–1.

Survivorship Curves

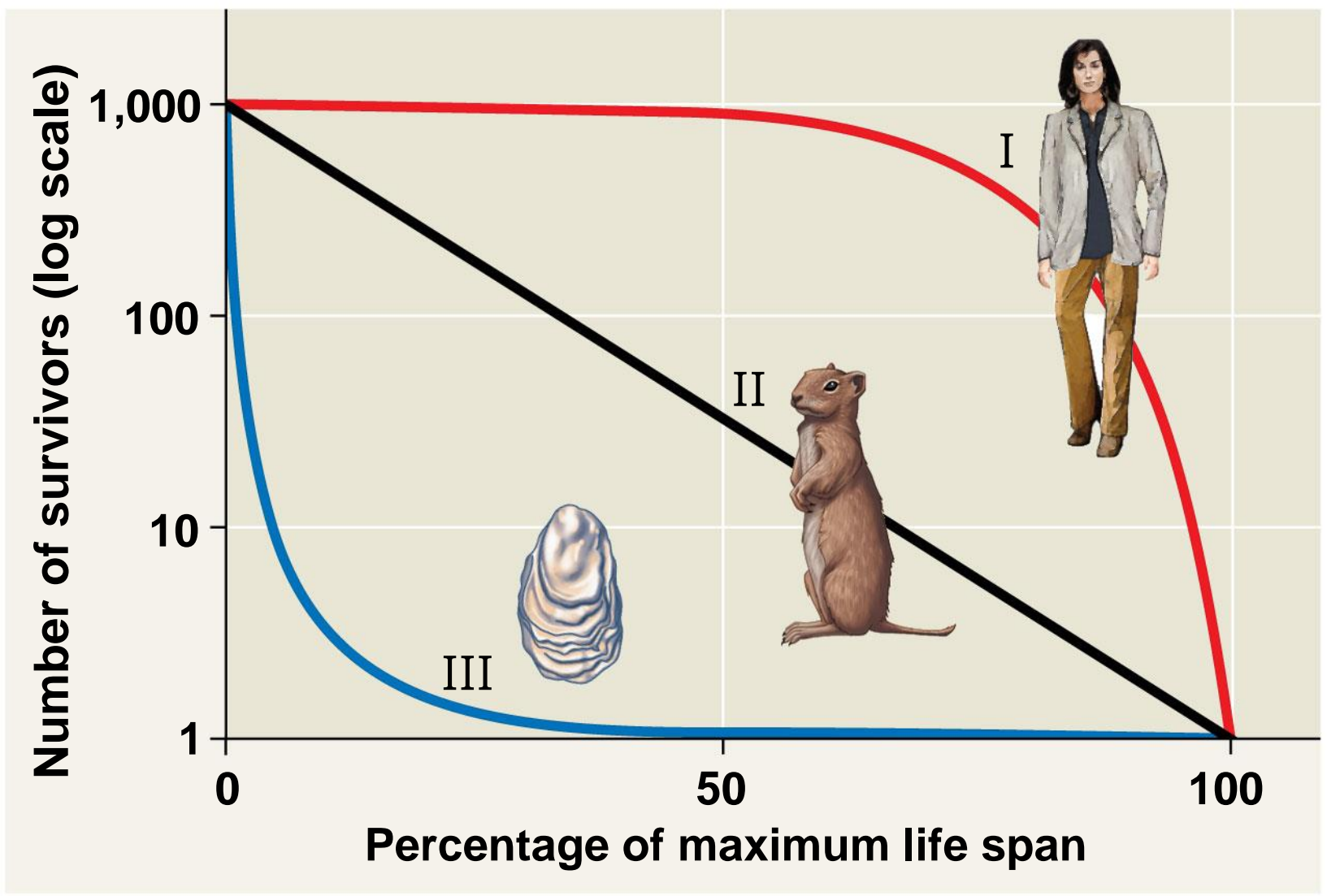
- A **survivorship curve** is a graphic way of representing the data in a life table
- The survivorship curve for Belding's ground squirrels shows a relatively constant death rate

Figure 53.5



- Survivorship curves can be classified into three general types
 - Type I: low death rates during early and middle life and an increase in death rates among older age groups
 - Type II: a constant death rate over the organism's life span
 - Type III: high death rates for the young and a lower death rate for survivors
- Many species are intermediate to these curves

Figure 53.6



Concept 53.2: The exponential model describes population growth in an idealized, unlimited environment

- It is useful to study population growth in an idealized situation
- Idealized situations help us understand the capacity of species to increase and the conditions that may facilitate this growth

Per Capita Rate of Increase

$$\begin{array}{ccccccc} \text{Change in} & & & & & & \\ \text{population} & = & \text{Births} & + & \text{Immigrants} & - & \text{Deaths} & - & \text{Emigrants} \\ \text{size} & & & & \text{entering} & & & & \text{leaving} \\ & & & & \text{population} & & & & \text{population} \end{array}$$

- If immigration and emigration are ignored, a population's growth rate (per capita increase) equals birth rate minus death rate

- The population growth rate can be expressed mathematically as

where ΔN is the change in population size, Δt is the time interval, B is the number of births, and D is the number of deaths

- Births and deaths can be expressed as the average number of births and deaths per individual during the specified time interval

$$B = bN$$

$$D = mN$$

where b is the annual per capita birth rate, m (for mortality) is the per capita death rate, and N is population size

- The population growth equation can be revised

- The per capita rate of increase (r) is given by

$$r = b - m$$

- **Zero population growth (ZPG)** occurs when the birth rate equals the death rate ($r = 0$)

- Change in population size can now be written as

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

- Instantaneous growth rate can be expressed as

$$\frac{dN}{dt} = r_{\text{inst}}N$$

- where r_{inst} is the instantaneous per capita rate of increase

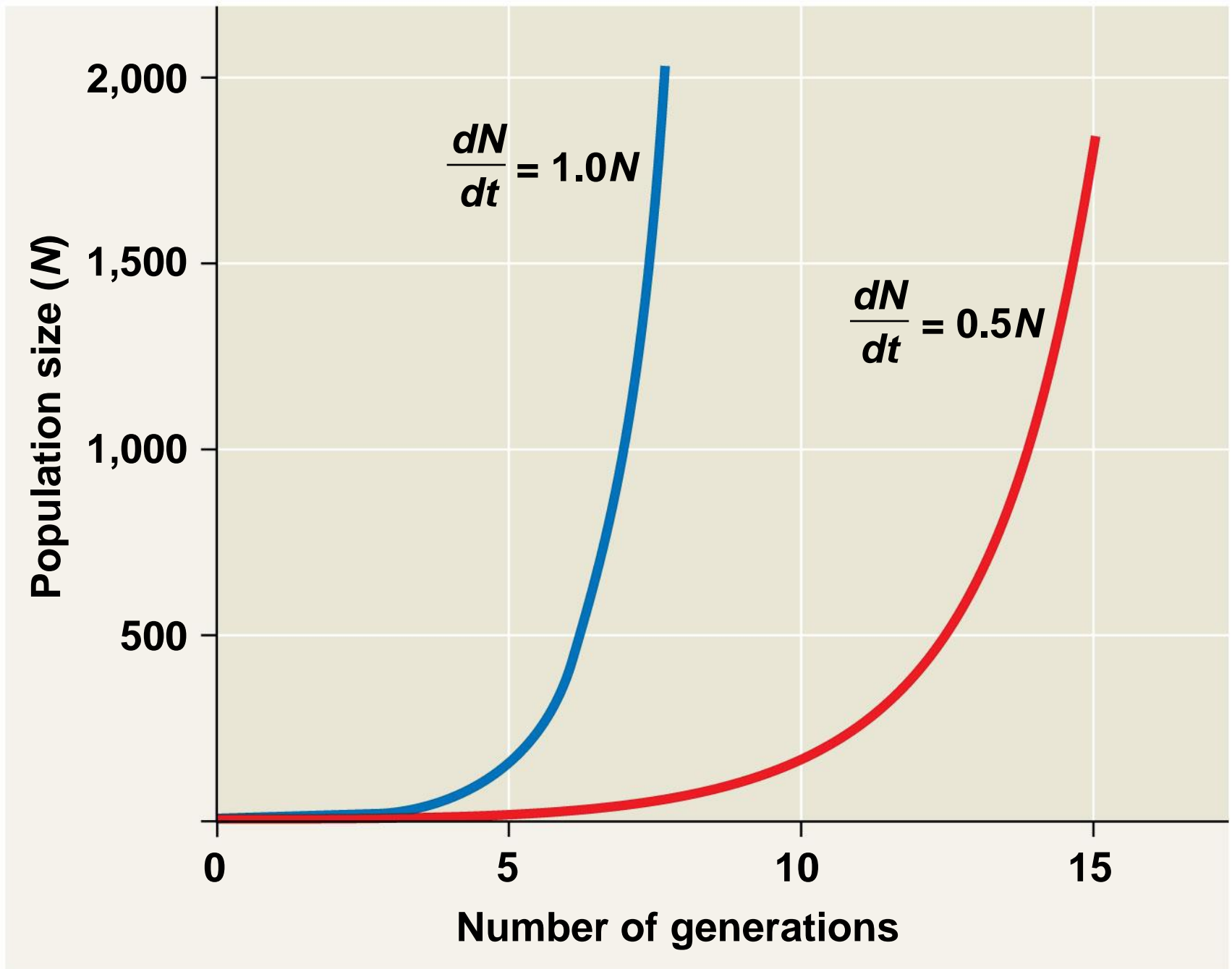
Exponential Growth

- **Exponential population growth** is population increase under idealized conditions
- Under these conditions, the rate of increase is at its maximum, denoted as r_{\max}
- The equation of exponential population growth is

$$\frac{dN}{dt} = r_{\max}N$$

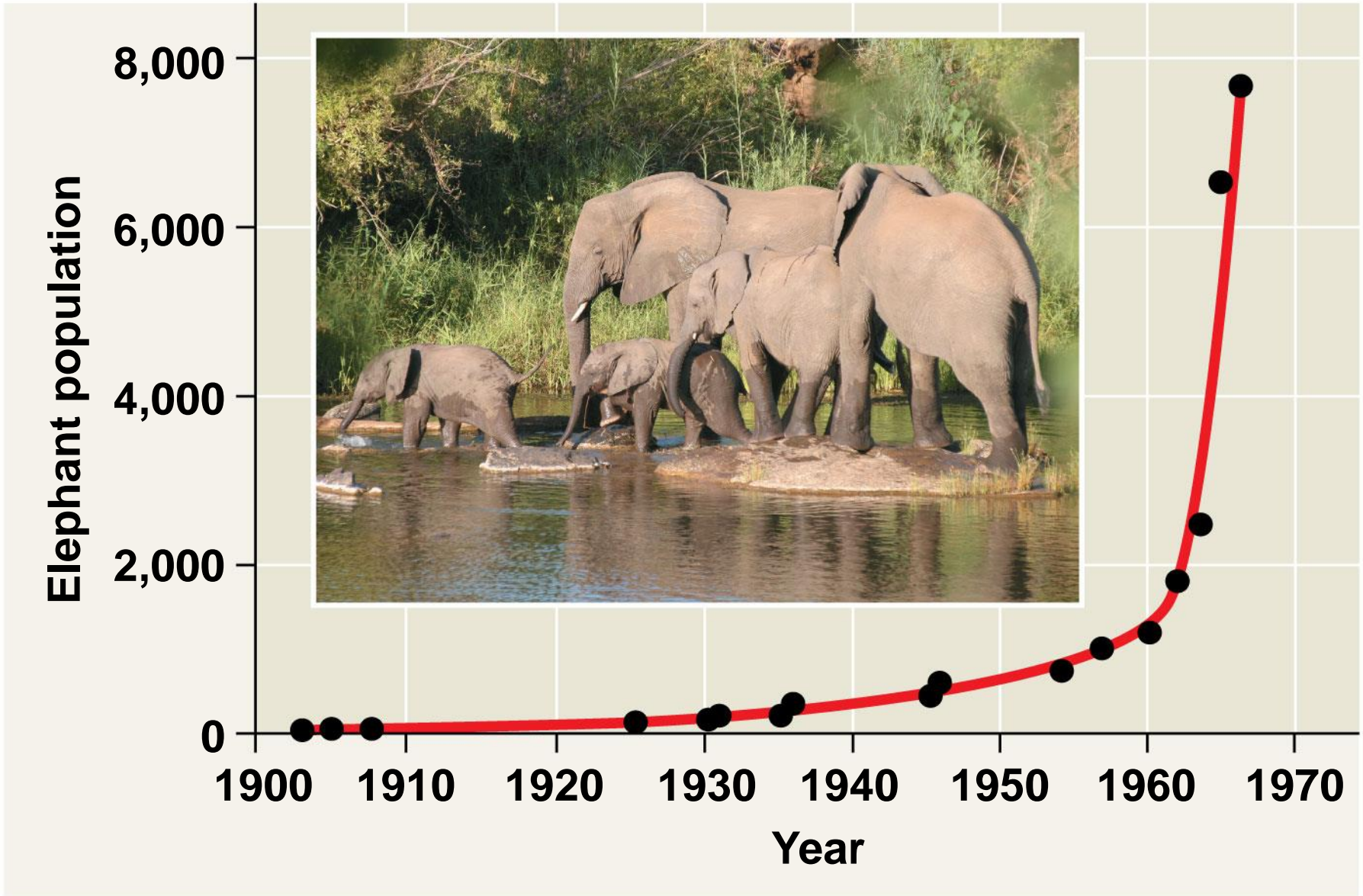
- Exponential population growth results in a J-shaped curve

Figure 53.7



- The J-shaped curve of exponential growth characterizes some rebounding populations
 - For example, the elephant population in Kruger National Park, South Africa, grew exponentially after hunting was banned

Figure 53.8



Concept 53.3: The logistic model describes how a population grows more slowly as it nears its carrying capacity

- Exponential growth cannot be sustained for long in any population
- A more realistic population model limits growth by incorporating carrying capacity
- **Carrying capacity** (K) is the maximum population size the environment can support
- Carrying capacity varies with the abundance of limiting resources

The Logistic Growth Model

- In the **logistic population growth** model, the per capita rate of increase declines as carrying capacity is reached
- The logistic model starts with the exponential model and adds an expression that reduces per capita rate of increase as N approaches K

$$\frac{dN}{dt} = r_{\max} N \frac{(K - N)}{K}$$

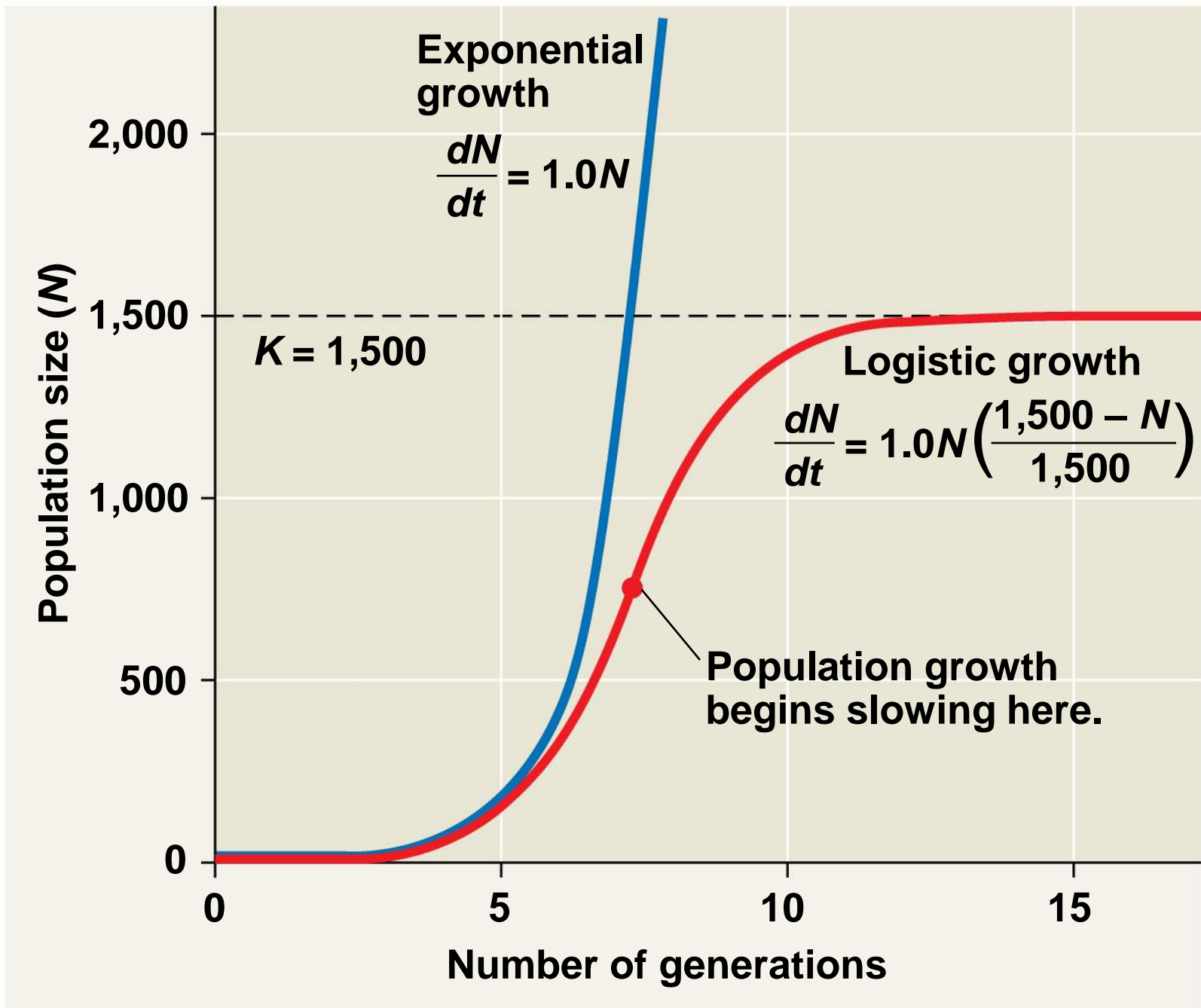
Table 53.3 Logistic Growth of a Hypothetical Population
($K = 1,500$)

Population Size (N)	Maximum Rate of Increase (r_{\max})	$\frac{K - N}{K}$	Per Capita Rate of Increase: $r_{\max} \left(\frac{K - N}{K} \right)$	Population Growth Rate:* $r_{\max} N \left(\frac{K - N}{K} \right)$
25	1.0	0.98	0.98	+25
100	1.0	0.93	0.93	+93
250	1.0	0.83	0.83	+208
500	1.0	0.67	0.67	+333
750	1.0	0.50	0.50	+375
1,000	1.0	0.33	0.33	+333
1,500	1.0	0.00	0.00	0

*Rounded to the nearest whole number.

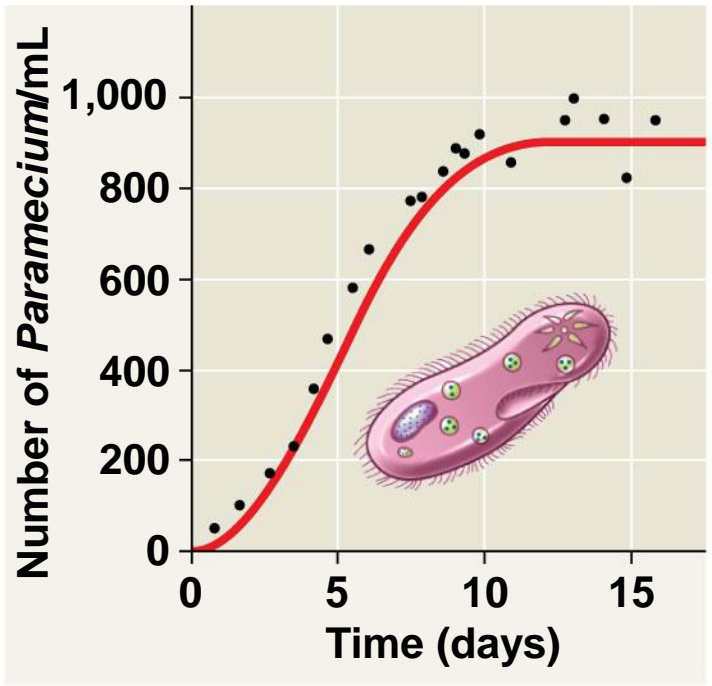
- The logistic model of population growth produces a sigmoid (S-shaped) curve

Figure 53.9

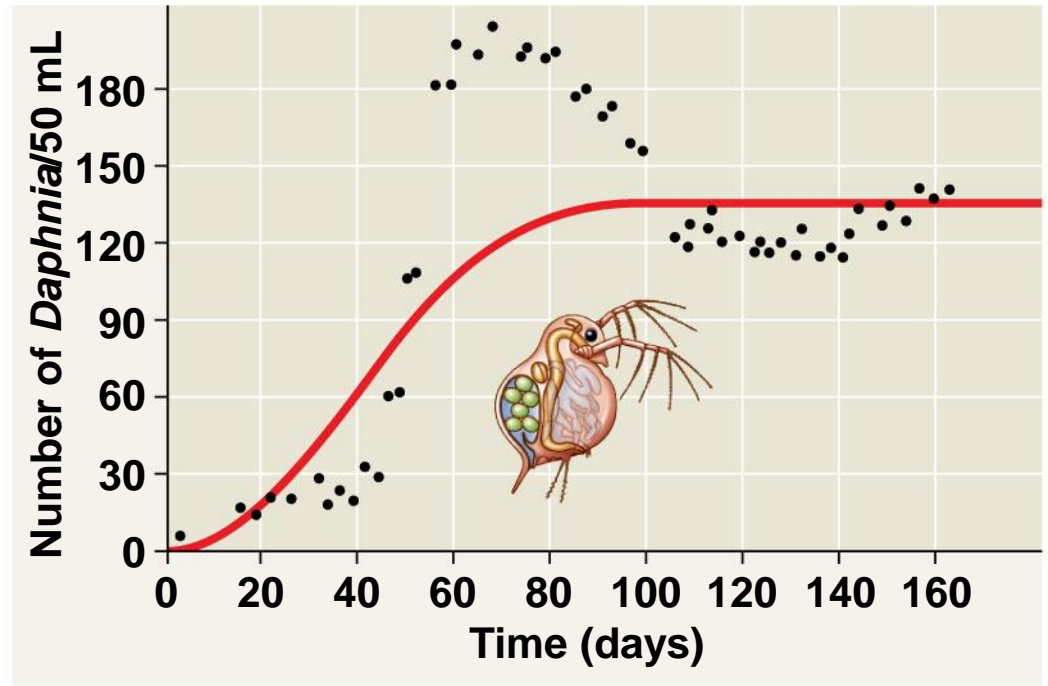


The Logistic Model and Real Populations

- The growth of laboratory populations of paramecia fits an S-shaped curve
- These organisms are grown in a constant environment lacking predators and competitors



(a) A *Paramecium* population in the lab



(b) A *Daphnia* population in the lab

- Some populations overshoot K before settling down to a relatively stable density

- Some populations fluctuate greatly and make it difficult to define K
- Some populations show an Allee effect, in which individuals have a more difficult time surviving or reproducing if the population size is too small

- The logistic model fits few real populations but is useful for estimating possible growth
- Conservation biologists can use the model to estimate the critical size below which populations may become extinct

Figure 53.11



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Concept 53.4: Life history traits are products of natural selection

- An organism's **life history** comprises the traits that affect its schedule of reproduction and survival
 - The age at which reproduction begins
 - How often the organism reproduces
 - How many offspring are produced during each reproductive cycle
- Life history traits are evolutionary outcomes reflected in the development, physiology, and behavior of an organism

Evolution and Life History Diversity

- Species that exhibit **semelparity**, or **big-bang reproduction**, reproduce once and die
- Species that exhibit **iteroparity**, or **repeated reproduction**, produce offspring repeatedly
- Highly variable or unpredictable environments likely favor big-bang reproduction, while dependable environments may favor repeated reproduction

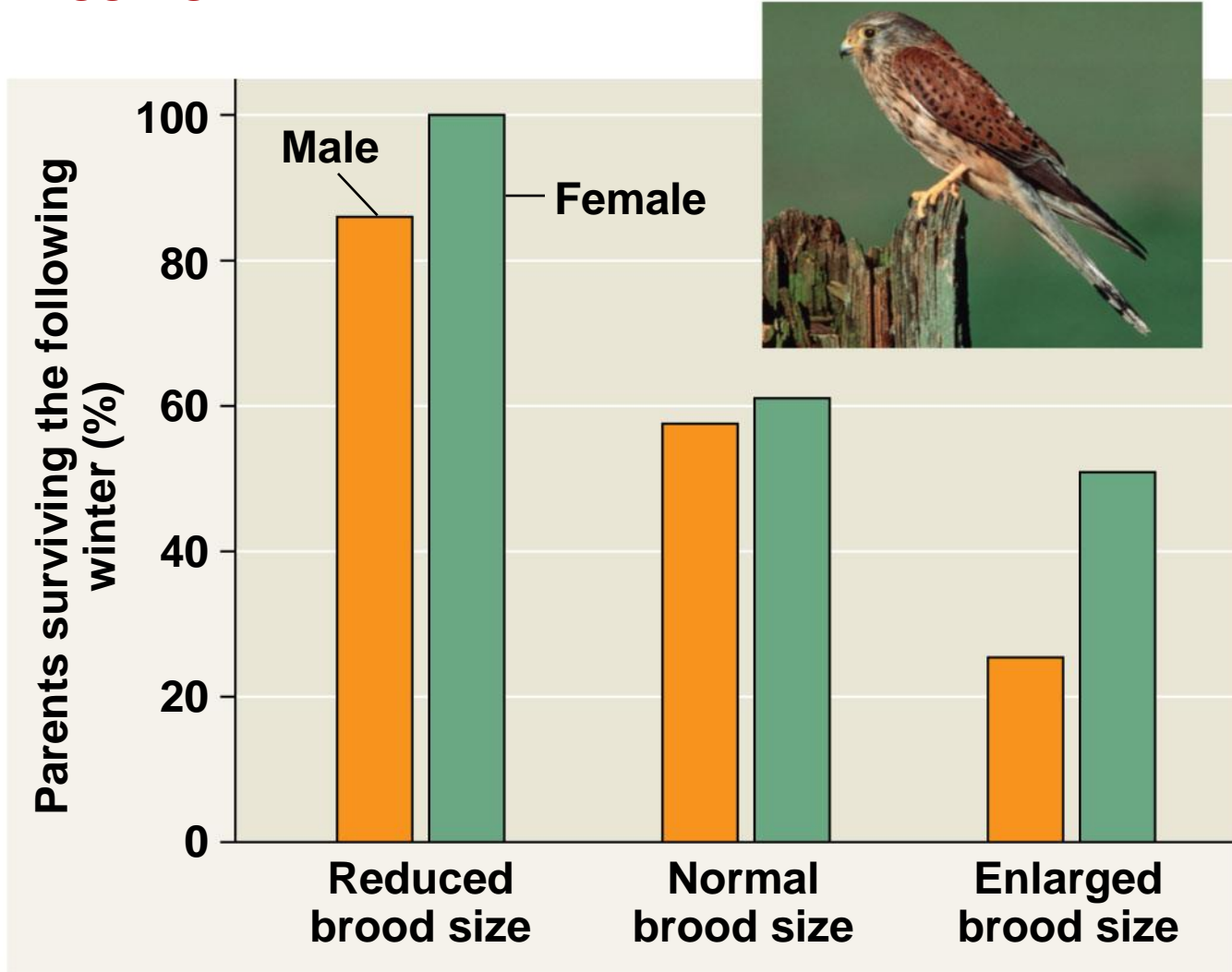
Figure 53.12



“Trade-offs” and Life Histories

- Organisms have finite resources, which may lead to trade-offs between survival and reproduction
 - For example, there is a trade-off between survival and paternal care in European kestrels

RESULTS



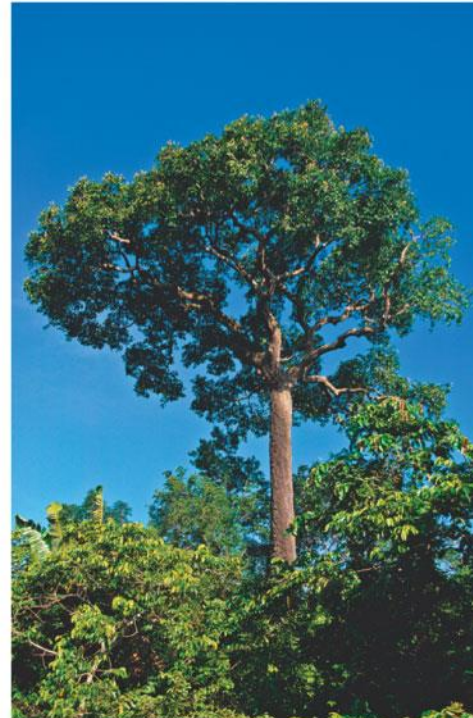
- Some plants produce a large number of small seeds, ensuring that at least some of them will grow and eventually reproduce



(a) Dandelion



**(b) Brazil nut tree (right)
and seeds in pod
(above)**



- Other types of plants produce a moderate number of large seeds that provide a large store of energy that will help seedlings become established

- **K-selection**, or density-dependent selection, selects for life history traits that are sensitive to population density
- **r-selection**, or density-independent selection, selects for life history traits that maximize reproduction

- The concepts of *K*-selection and *r*-selection are oversimplifications but have stimulated alternative hypotheses of life history evolution

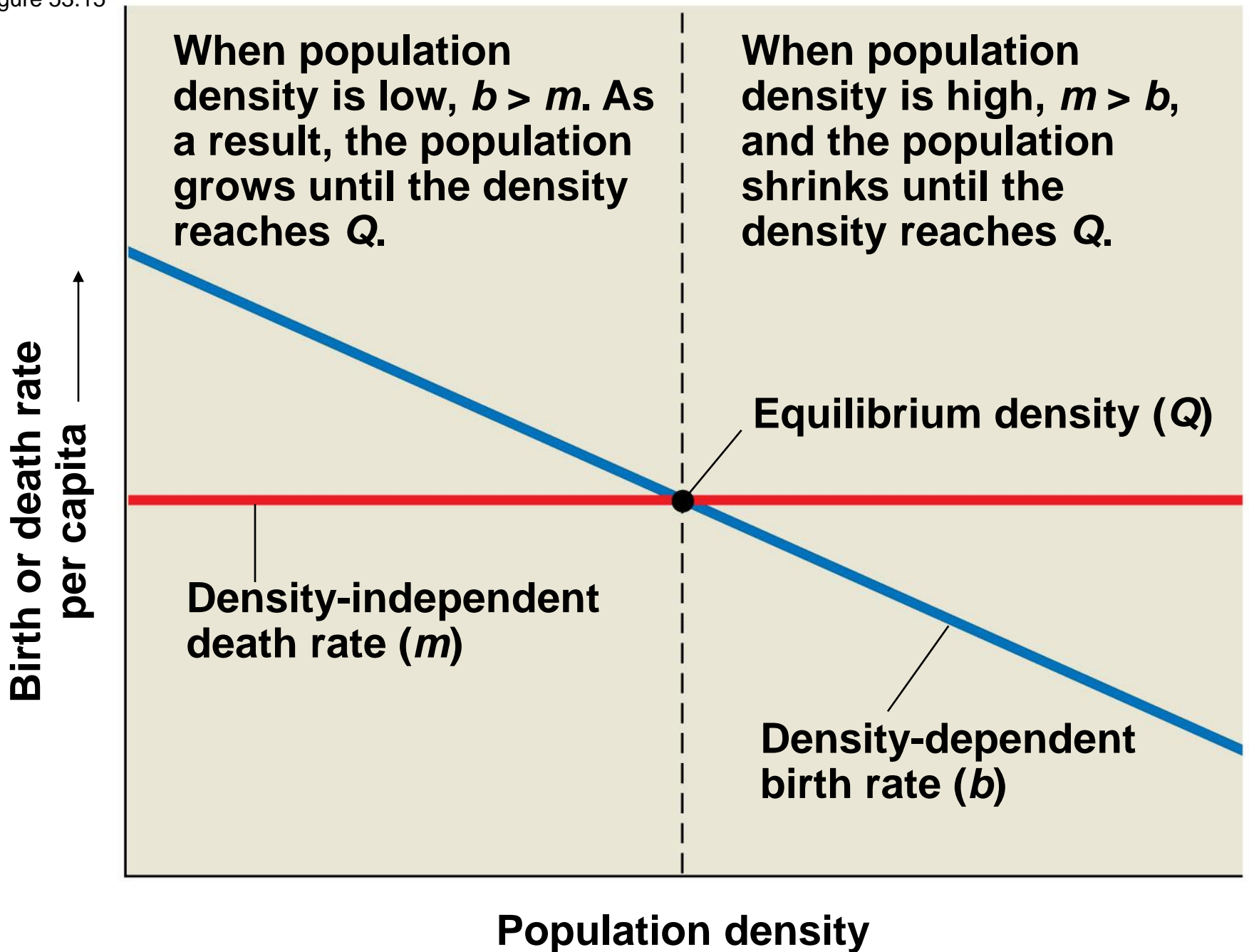
Concept 53.5: Many factors that regulate population growth are density dependent

- There are two general questions about regulation of population growth
 - What environmental factors stop a population from growing indefinitely?
 - Why do some populations show radical fluctuations in size over time, while others remain stable?

Population Change and Population Density

- In **density-independent** populations, birth rate and death rate do not change with population density
- In **density-dependent** populations, birth rates fall and death rates rise with population density

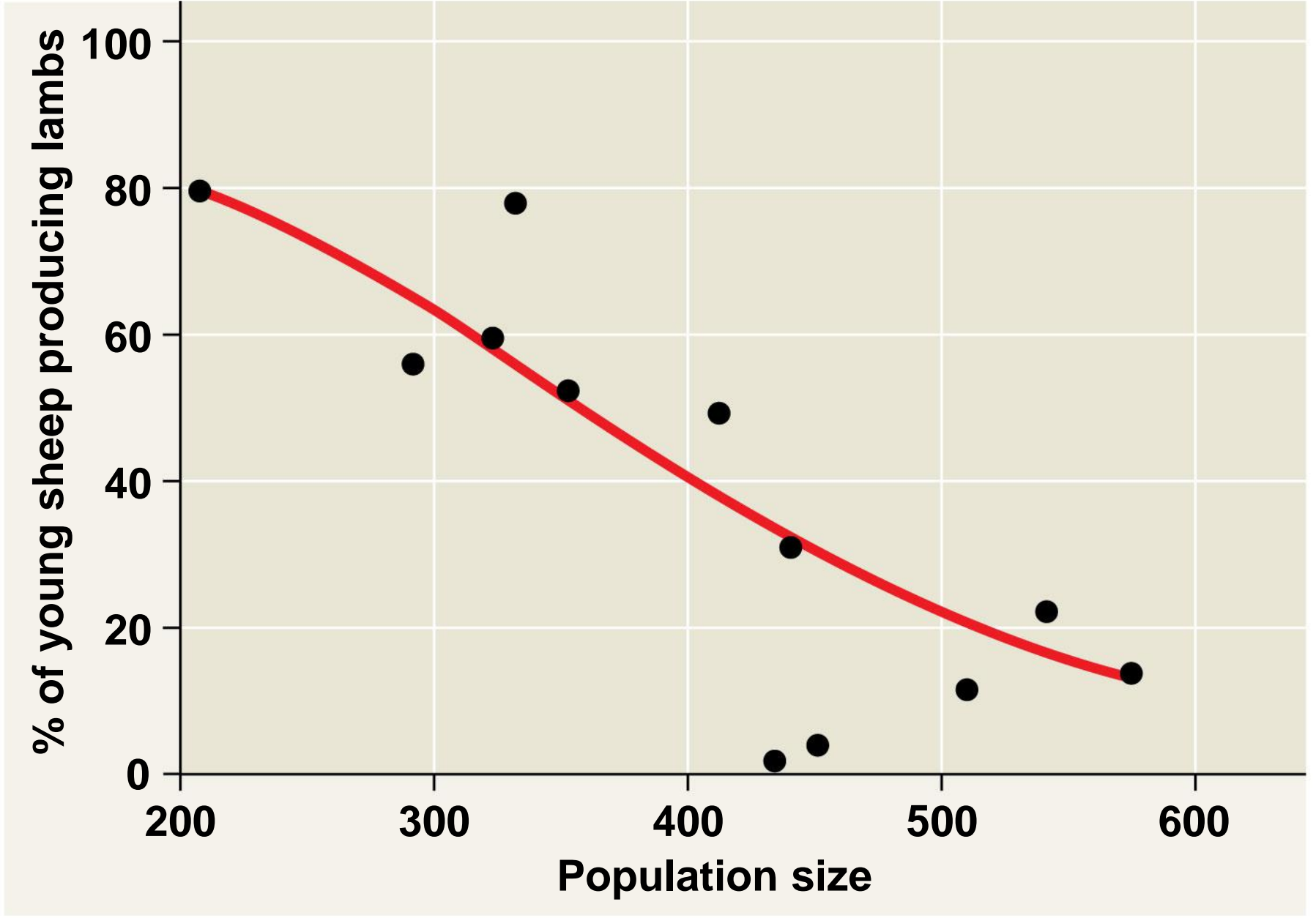
Figure 53.15



Mechanisms of Density-Dependent Population Regulation

- Density-dependent birth and death rates are an example of negative feedback that regulates population growth
- Density-dependent birth and death rates are affected by many factors, such as competition for resources, territoriality, disease, predation, toxic wastes, and intrinsic factors

Figure 53.16



Competition for Resources

- In crowded populations, increasing population density intensifies competition for resources and results in a lower birth rate

Figure 53.17a



Toxic Wastes

- Accumulation of toxic wastes can contribute to density-dependent regulation of population size

Predation

- As a prey population builds up, predators may feed preferentially on that species

Intrinsic Factors

- For some populations, intrinsic (physiological) factors appear to regulate population size

Territoriality

- In many vertebrates and some invertebrates, competition for territory may limit density

Figure 53.17e



Disease

- Population density can influence the health and survival of organisms
- In dense populations, pathogens can spread more rapidly

Figure 53.17f



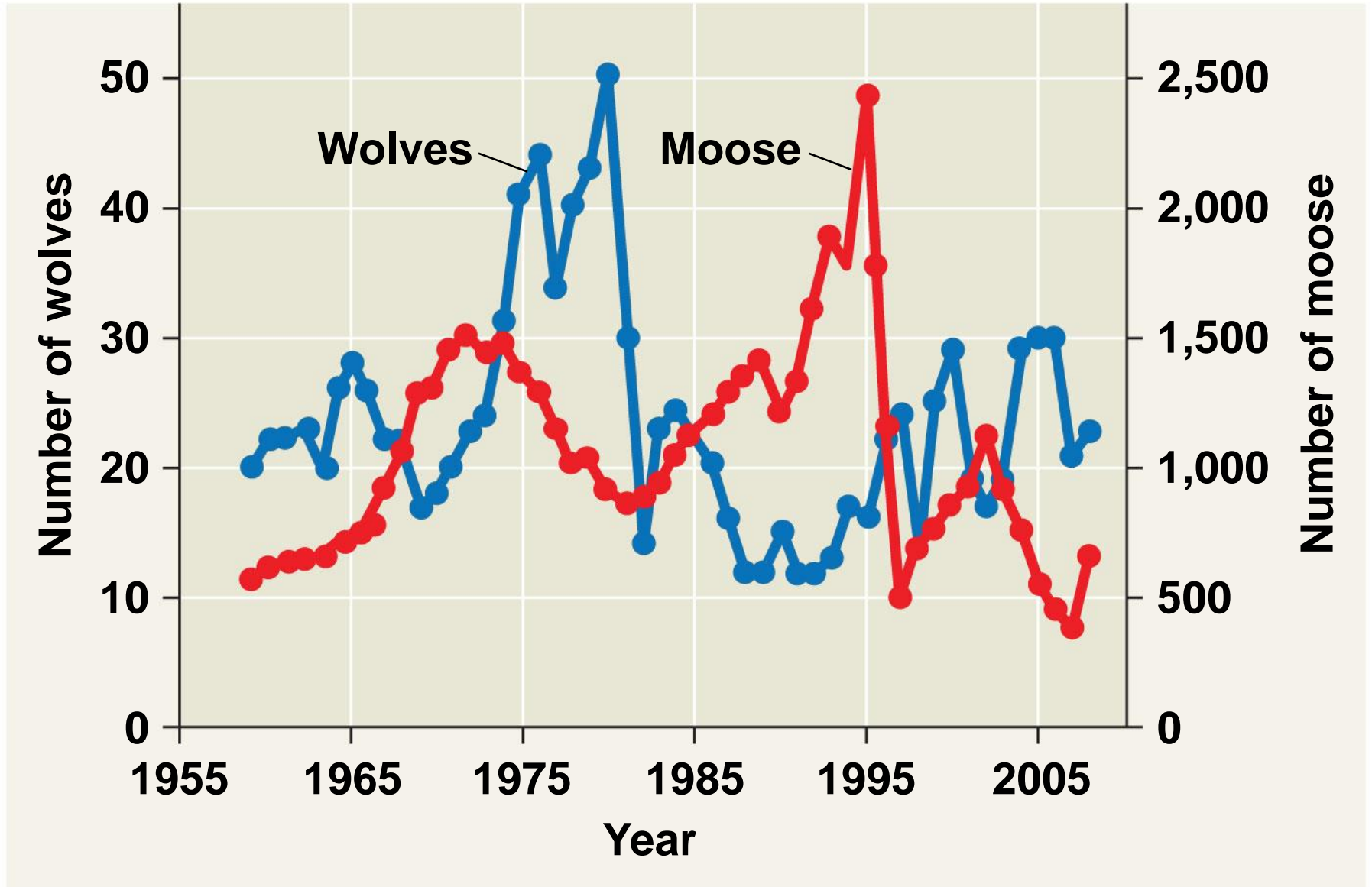
Population Dynamics

- The study of **population dynamics** focuses on the complex interactions between biotic and abiotic factors that cause variation in population size

Stability and Fluctuation

- Long-term population studies have challenged the hypothesis that populations of large mammals are relatively stable over time
- Both weather and predator population can affect population size over time
 - For example, the moose population on Isle Royale collapsed during a harsh winter, and when wolf numbers peaked

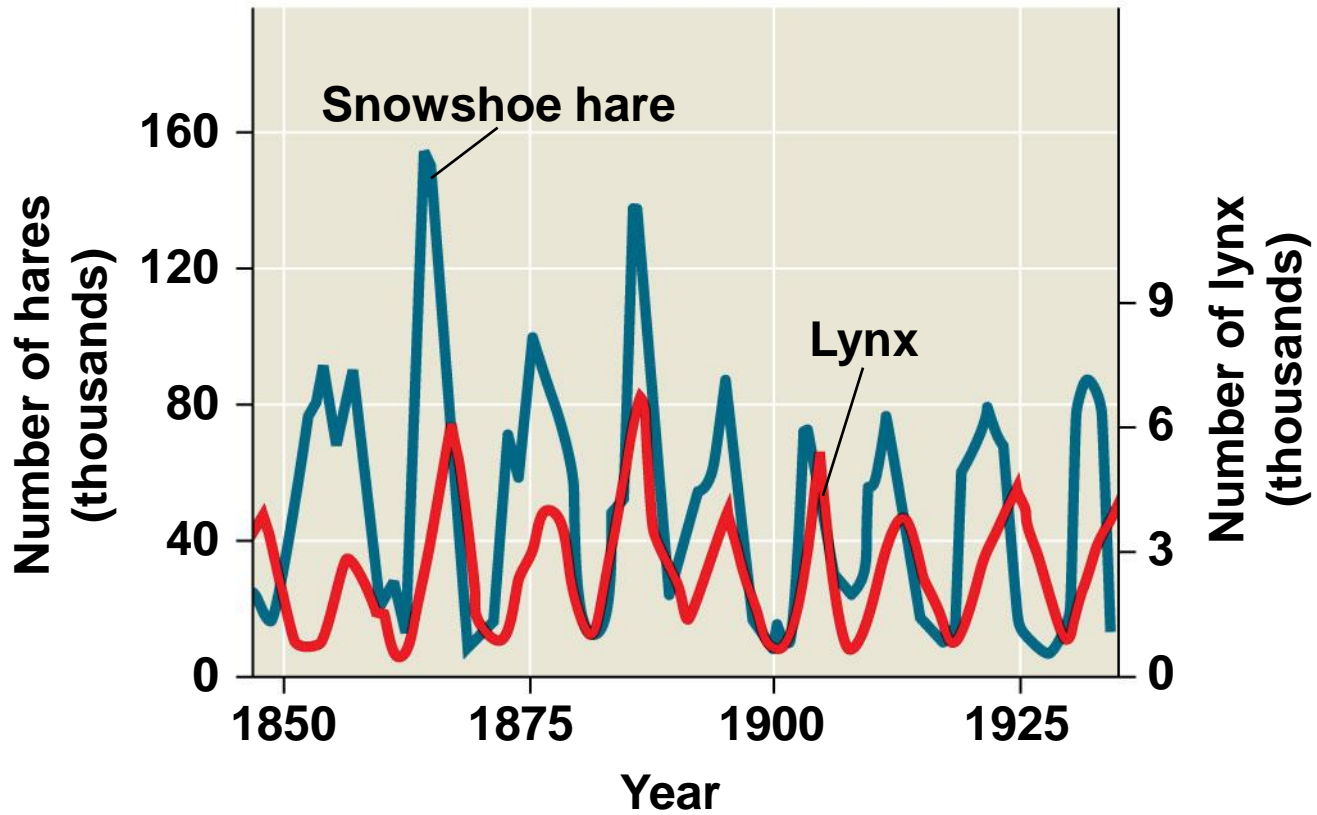
Figure 53.18



Population Cycles: Scientific Inquiry

- Some populations undergo regular boom-and-bust cycles
- Lynx populations follow the 10-year boom-and-bust cycle of hare populations
- Three hypotheses have been proposed to explain the hare's 10-year interval

Figure 53.19



- Hypothesis: The hare's population cycle follows a cycle of winter food supply
- If this hypothesis is correct, then the cycles should stop if the food supply is increased
- Additional food was provided experimentally to a hare population, and the whole population increased in size but continued to cycle
- These data do not support the first hypothesis

- Hypothesis: The hare's population cycle is driven by pressure from other predators
- In a study conducted by field ecologists, 90% of the hares were killed by predators
- These data support the second hypothesis

- Hypothesis: The hare's population cycle is linked to sunspot cycles
- Sunspot activity affects light quality, which in turn affects the quality of the hares' food
- There is good correlation between sunspot activity and hare population size

- The results of all these experiments suggest that both predation and sunspot activity regulate hare numbers and that food availability plays a less important role

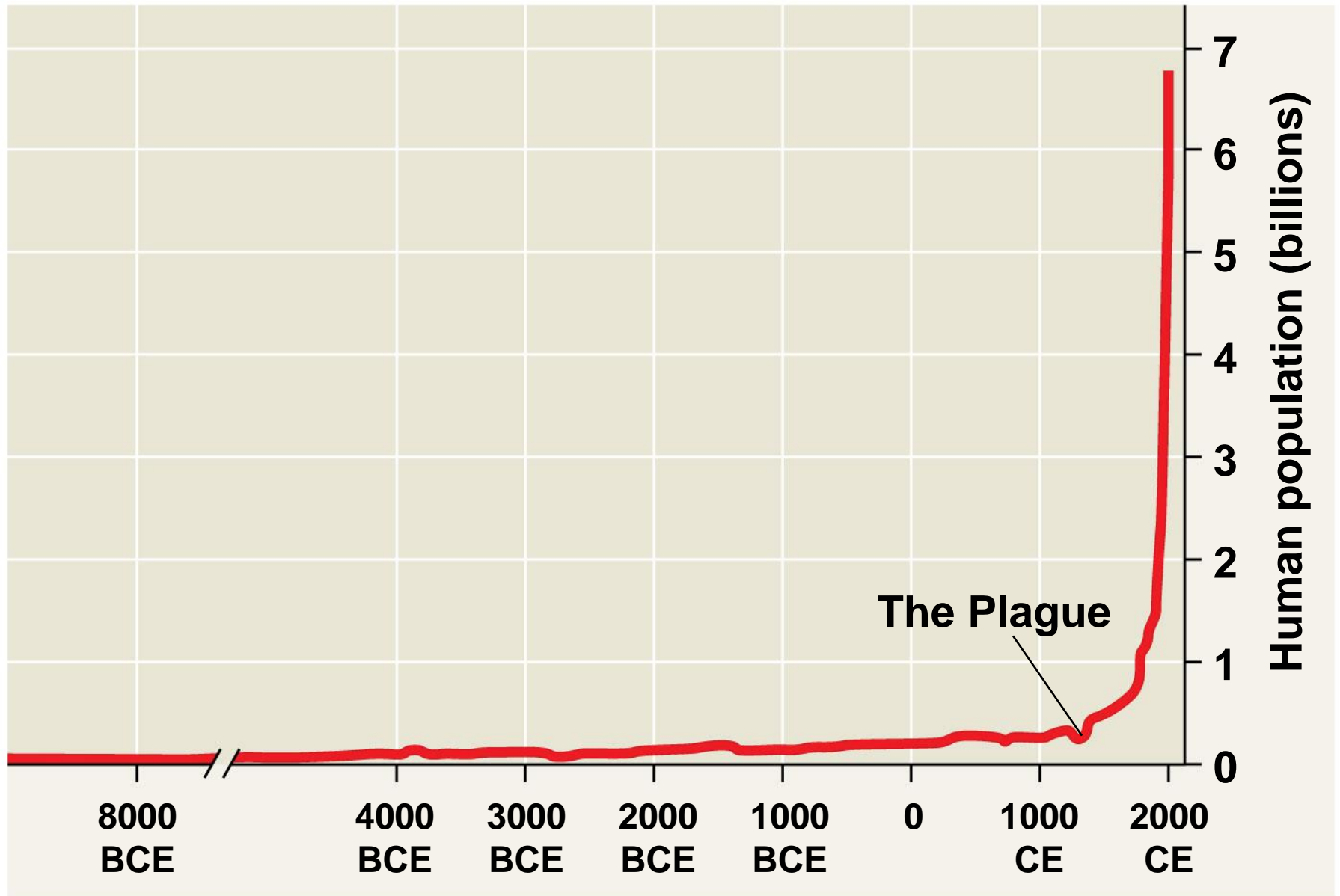
Concept 53.6: The human population is no longer growing exponentially but is still increasing rapidly

- No population can grow indefinitely, and humans are no exception

The Global Human Population

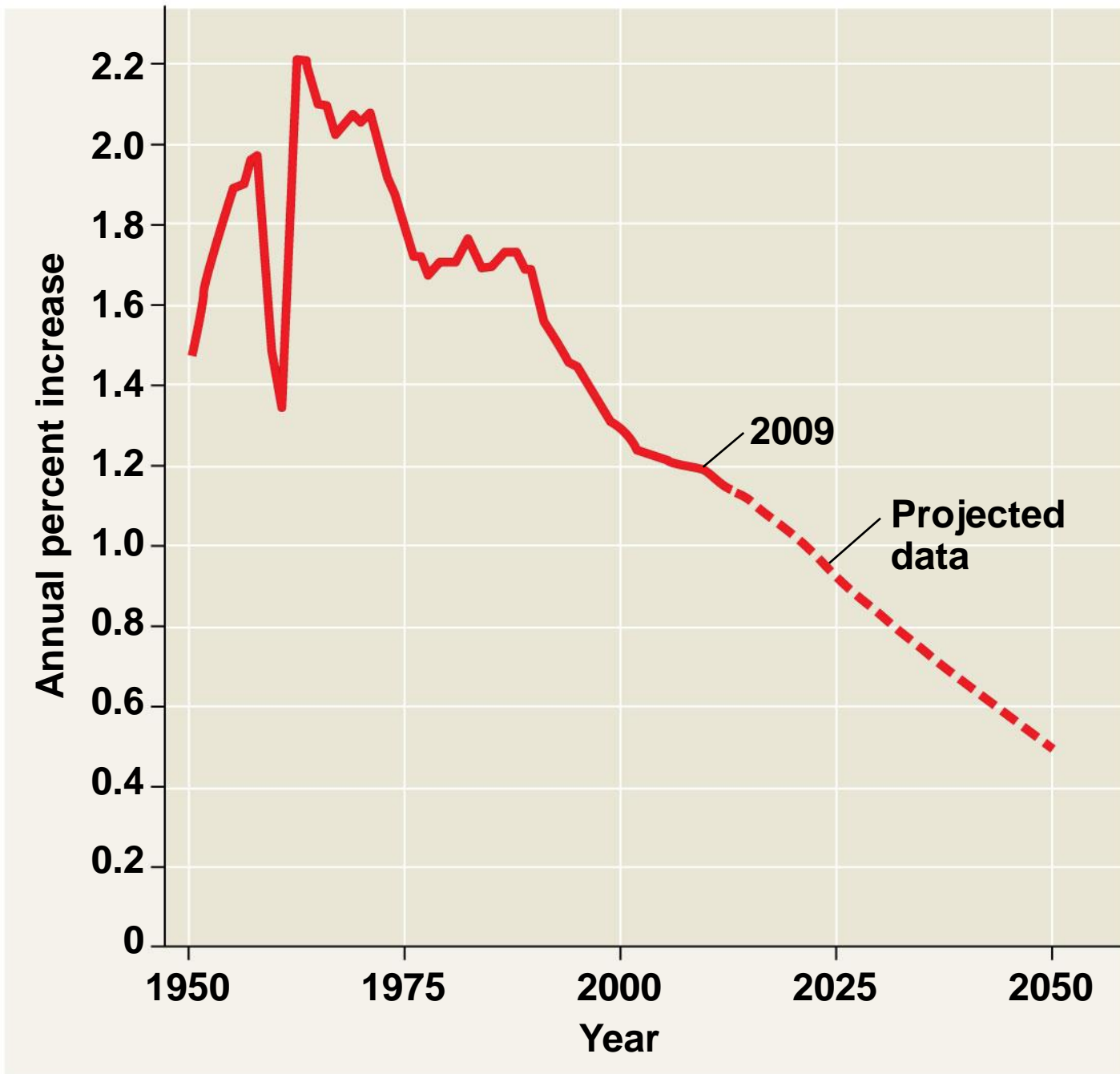
- The human population increased relatively slowly until about 1650 and then began to grow exponentially

Figure 53.22



- The global population is more than 6.8 billion people
- Though the global population is still growing, the rate of growth began to slow during the 1960s

Figure 53.23



Regional Patterns of Population Change

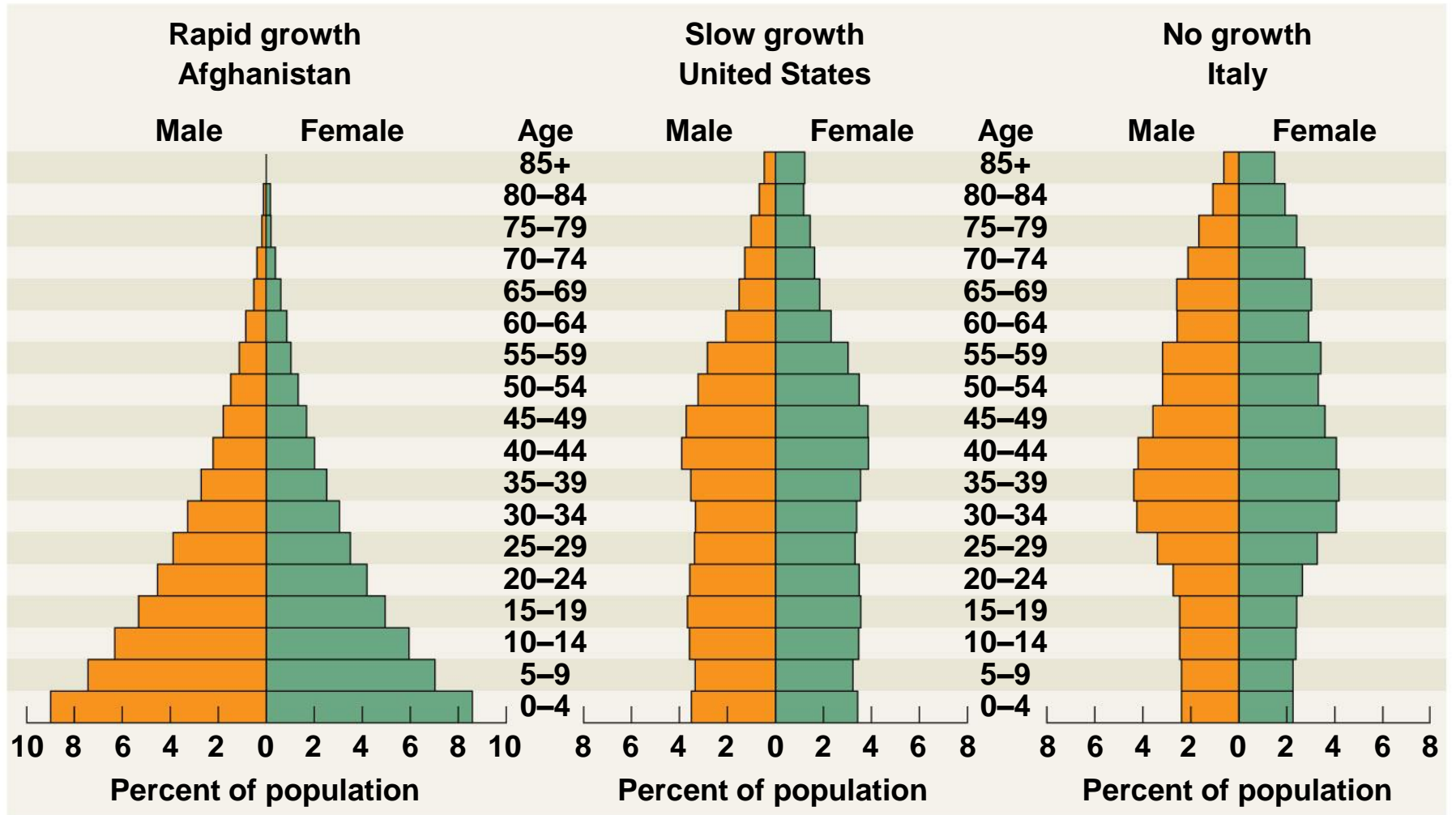
- To maintain population stability, a regional human population can exist in one of two configurations
 - Zero population growth =
High birth rate – High death rate
 - Zero population growth =
Low birth rate – Low death rate
- The **demographic transition** is the move from the first state to the second state

- The demographic transition is associated with an increase in the quality of health care and improved access to education, especially for women
- Most of the current global population growth is concentrated in developing countries

Age Structure

- One important demographic factor in present and future growth trends is a country's **age structure**
- Age structure is the relative number of individuals at each age

Figure 53.24

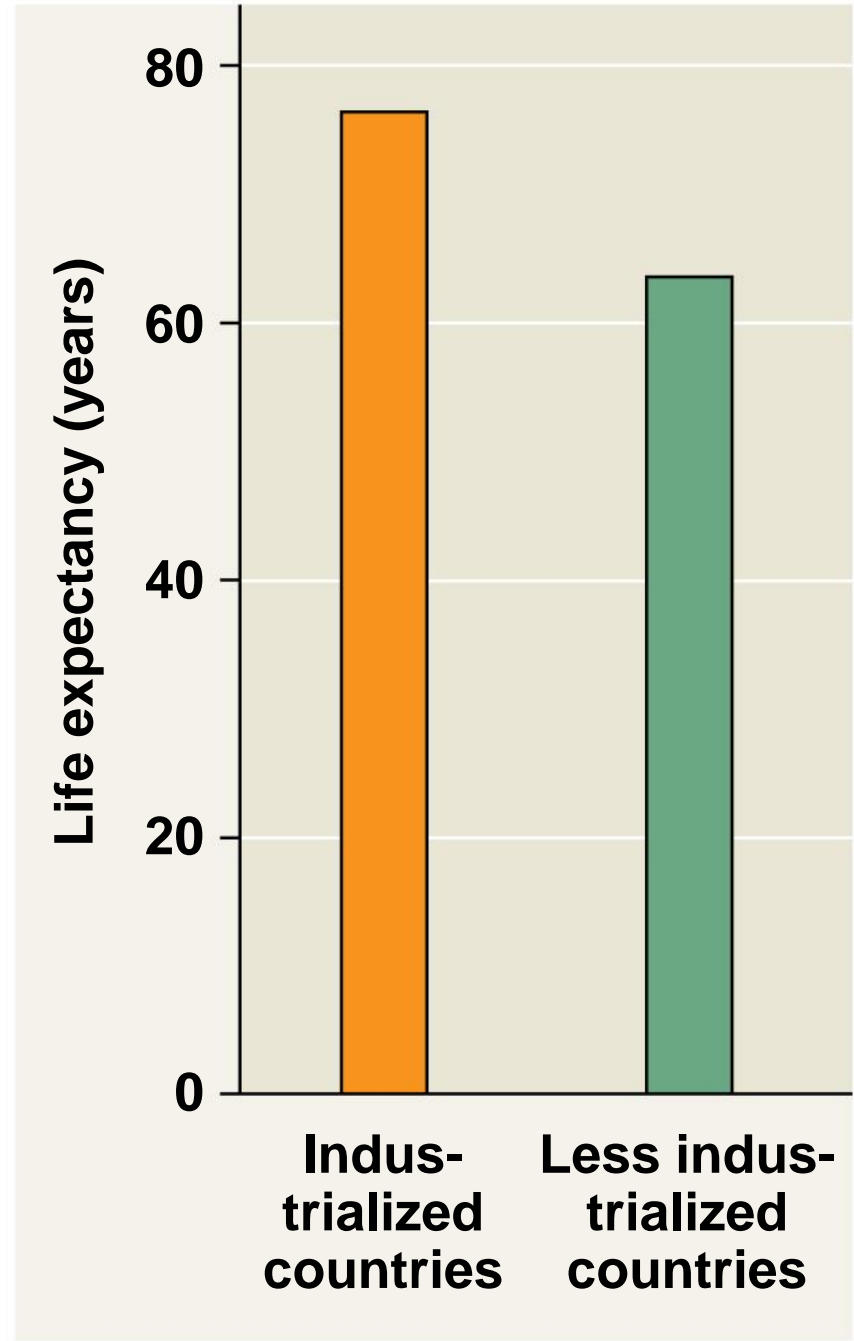
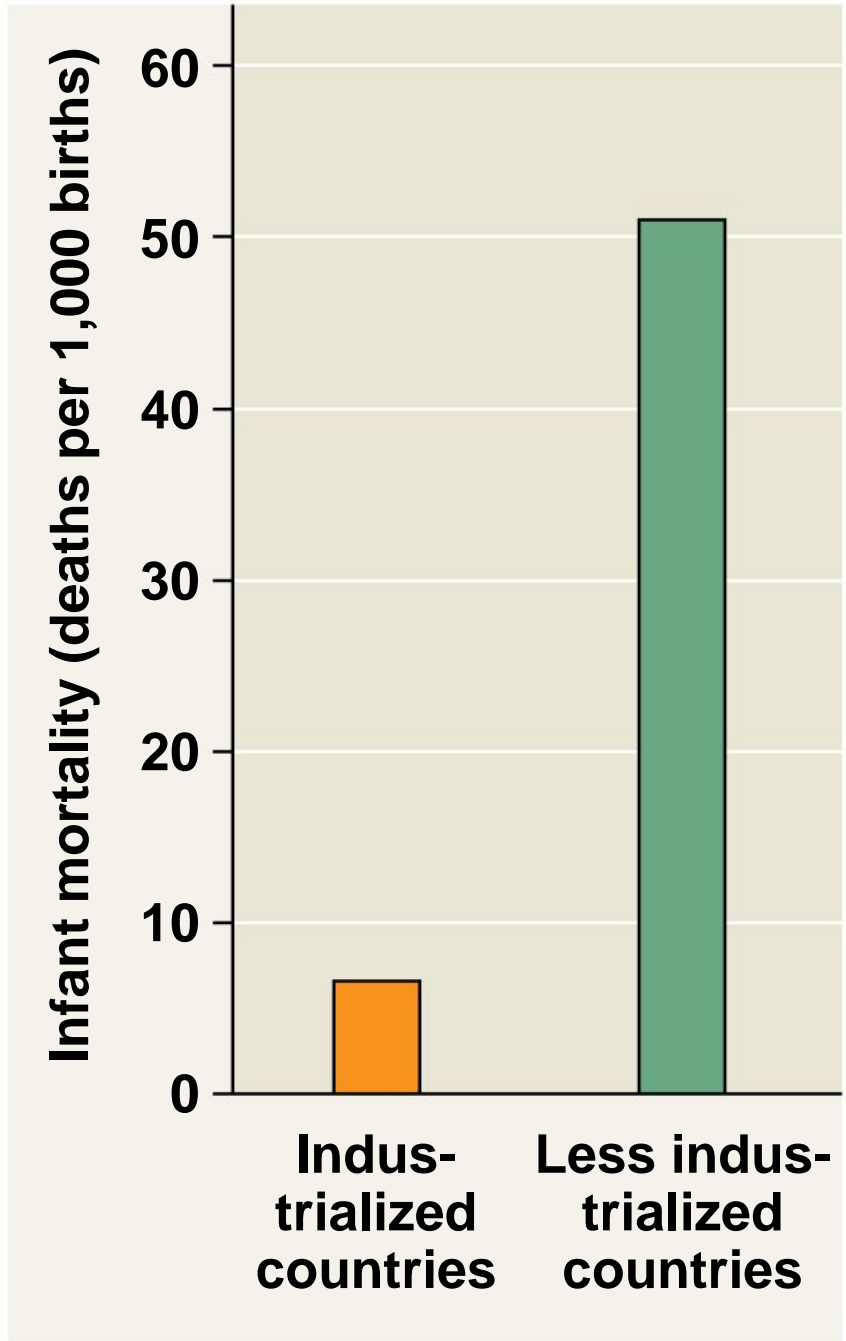


- Age structure diagrams can predict a population's growth trends
- They can illuminate social conditions and help us plan for the future

Infant Mortality and Life Expectancy

- Infant mortality and life expectancy at birth vary greatly among developed and developing countries but do not capture the wide range of the human condition

Figure 53.25



Global Carrying Capacity

- How many humans can the biosphere support?
- Population ecologists predict a global population of 7.8–10.8 billion people in 2050

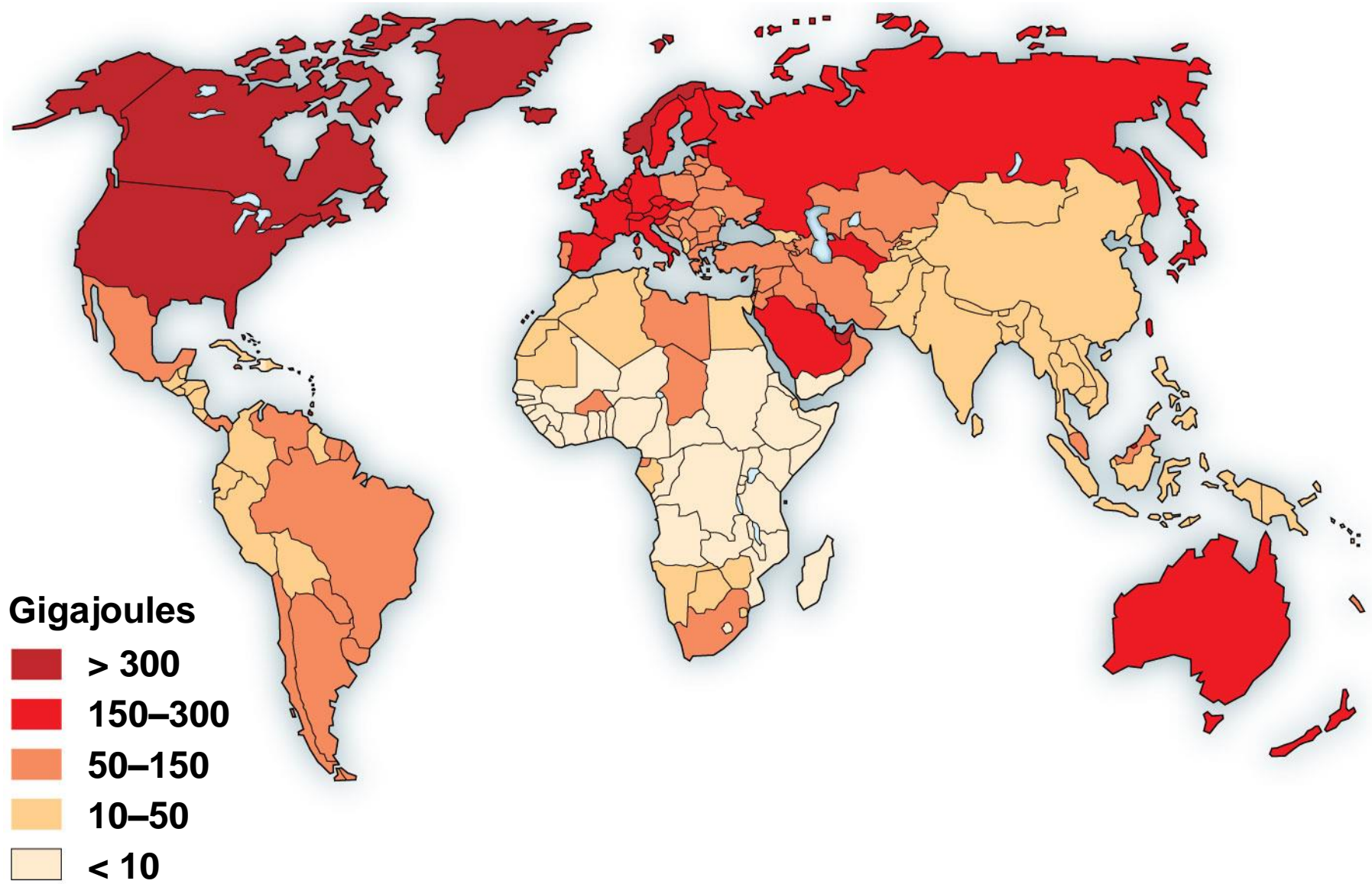
Estimates of Carrying Capacity

- The carrying capacity of Earth for humans is uncertain
- The average estimate is 10–15 billion

Limits on Human Population Size

- The **ecological footprint** concept summarizes the aggregate land and water area needed to sustain the people of a nation
- It is one measure of how close we are to the carrying capacity of Earth
- Countries vary greatly in footprint size and available ecological capacity

Figure 53.26



- Our carrying capacity could potentially be limited by food, space, nonrenewable resources, or buildup of wastes
- Unlike other organisms, we can regulate our population growth through social changes