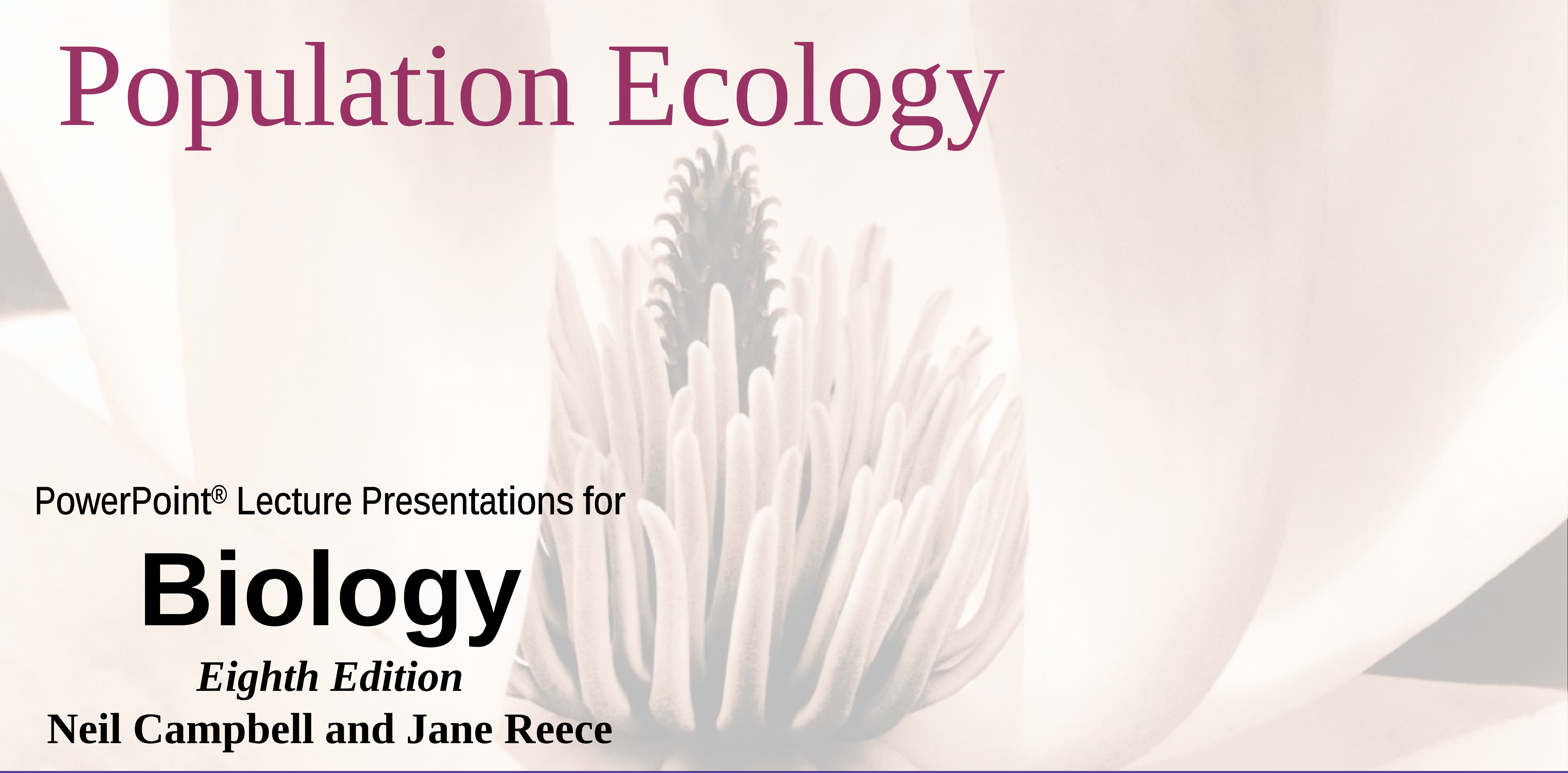
Chapter 53

Population Ecology



PowerPoint® Lecture Presentations for

Biology

Eighth Edition

Neil Campbell and Jane Reece

Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

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

Fig. 53-1

- **Population ecology** is the study of populations in relation to 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

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, or the **mark-recapture method**

Fig. 53-2

APPLICATION

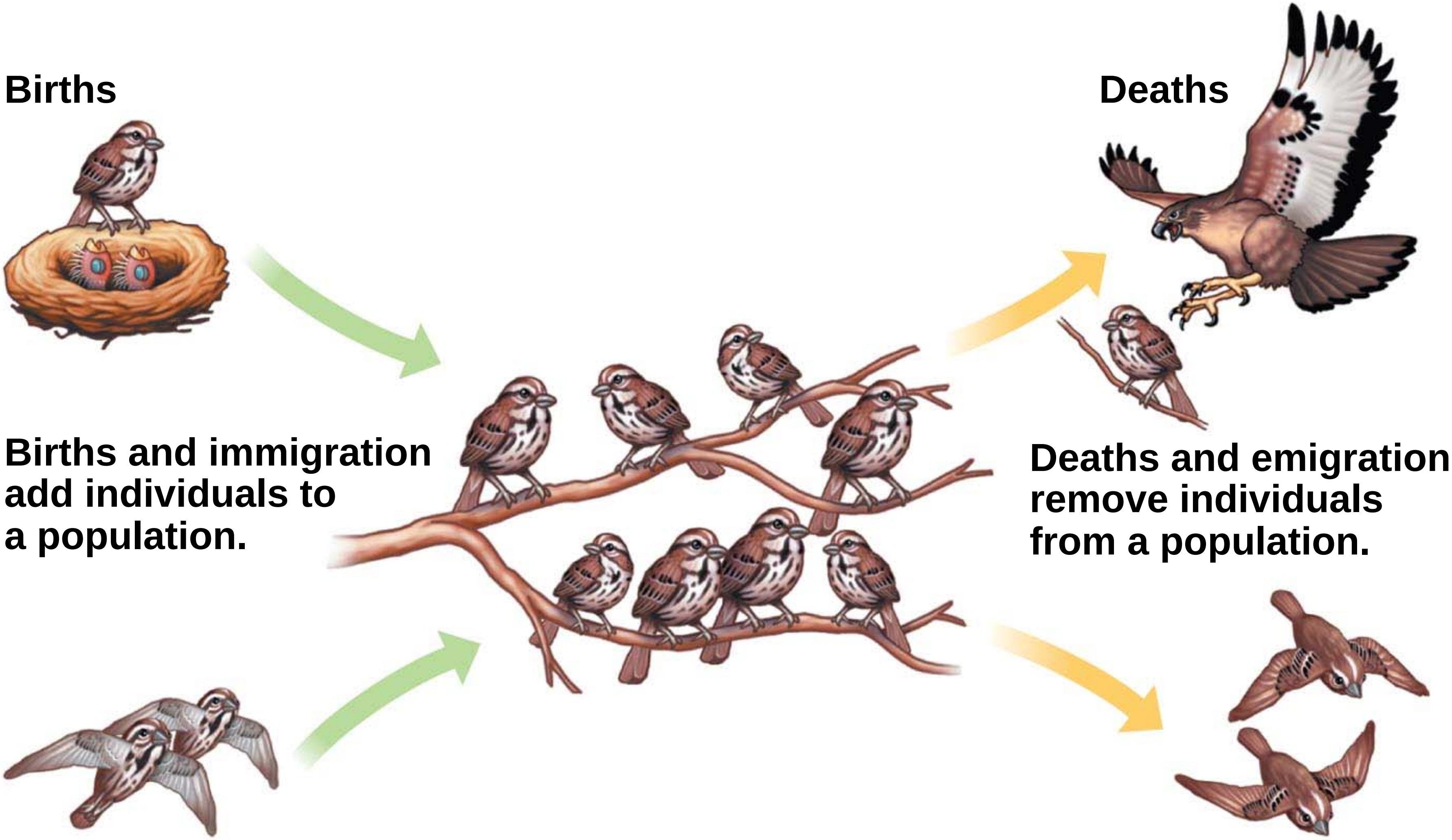
Hector’s dolphins

- 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

Fig. 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

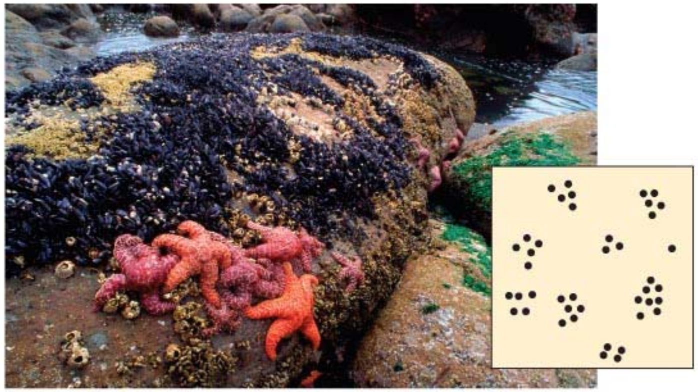
- Environmental and social factors influence spacing of individuals in a population

- In a *clumped* dispersion, individuals aggregate in patches
- A clumped dispersion may be influenced by resource availability and behavior

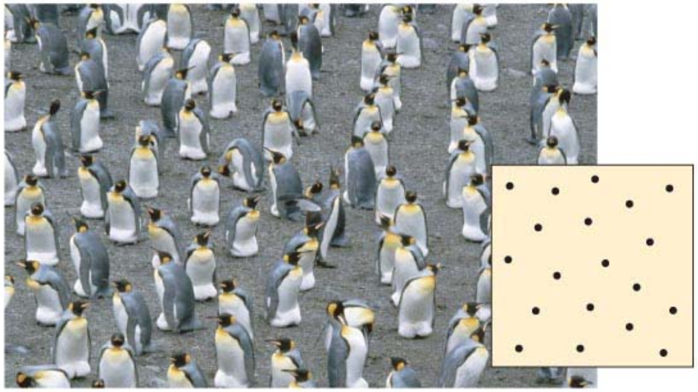
PLAY

Video: Flapping Geese (Clumped)

Fig. 53-4



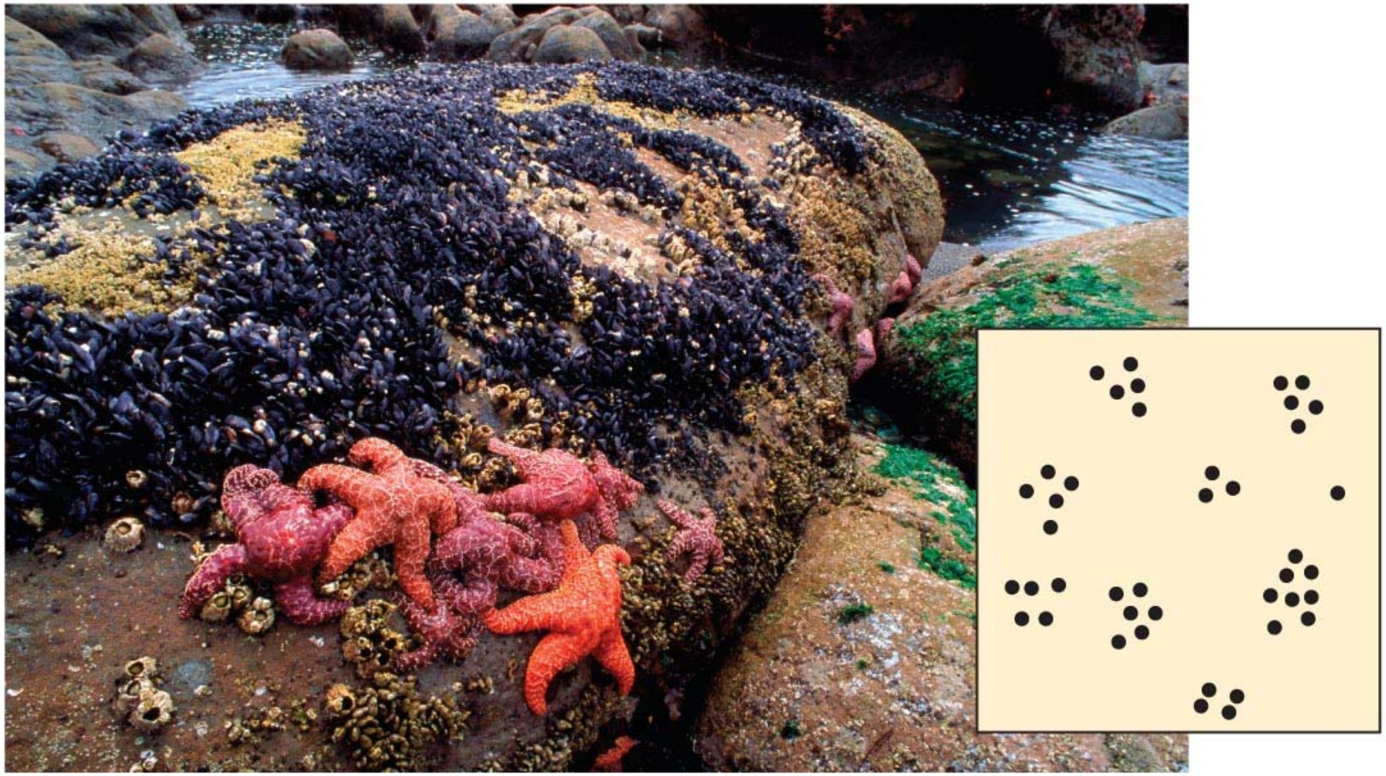
(a) Clumped



(b) Uniform

(c) Random

Fig. 53-4a



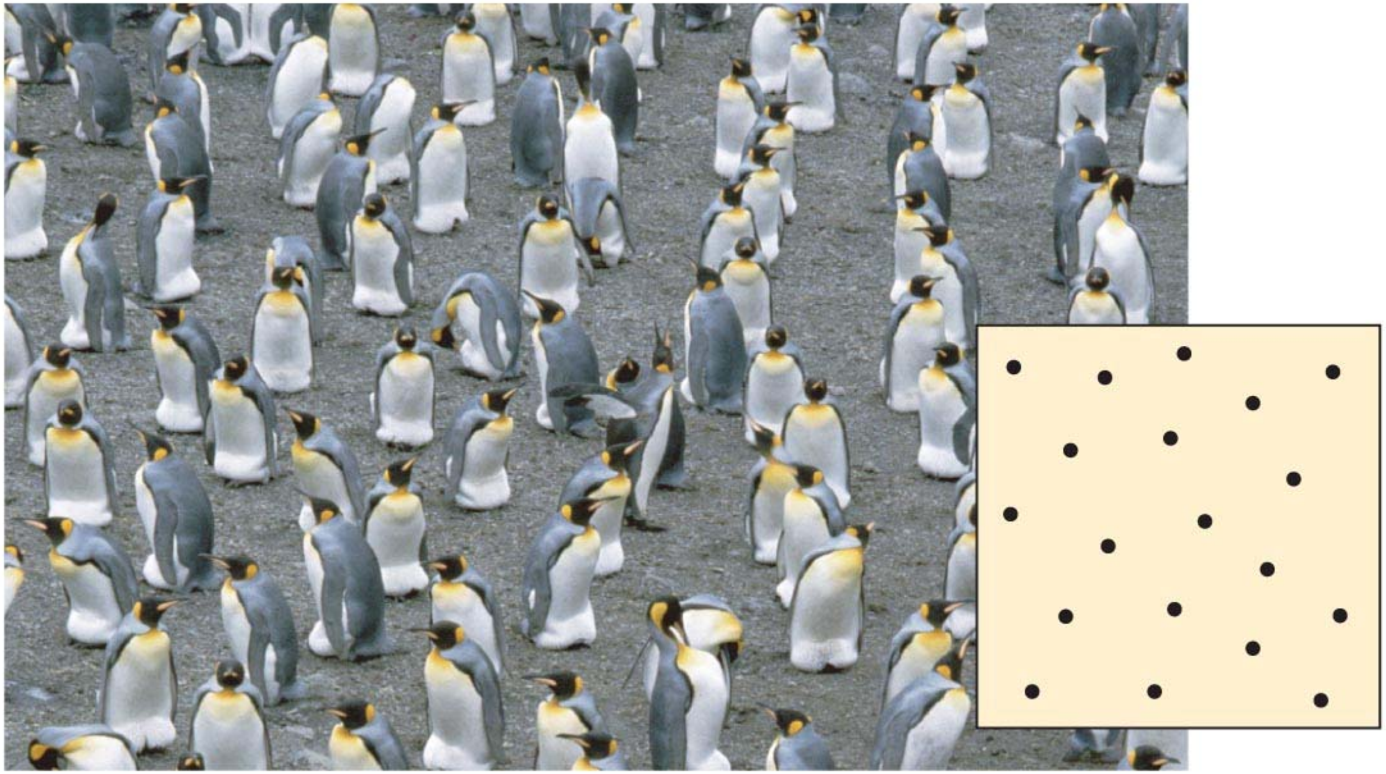
(a) Clumped

- A *uniform* dispersion is one in which individuals are evenly distributed
- It may be influenced by social interactions such as **territoriality**

PLAY

Video: Albatross Courtship (Uniform)

Fig. 53-4b



(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

PLAY

Video: Prokaryotic Flagella (*Salmonella typhimurium*) (Random)

Fig. 53-4c

(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

Table 53-1

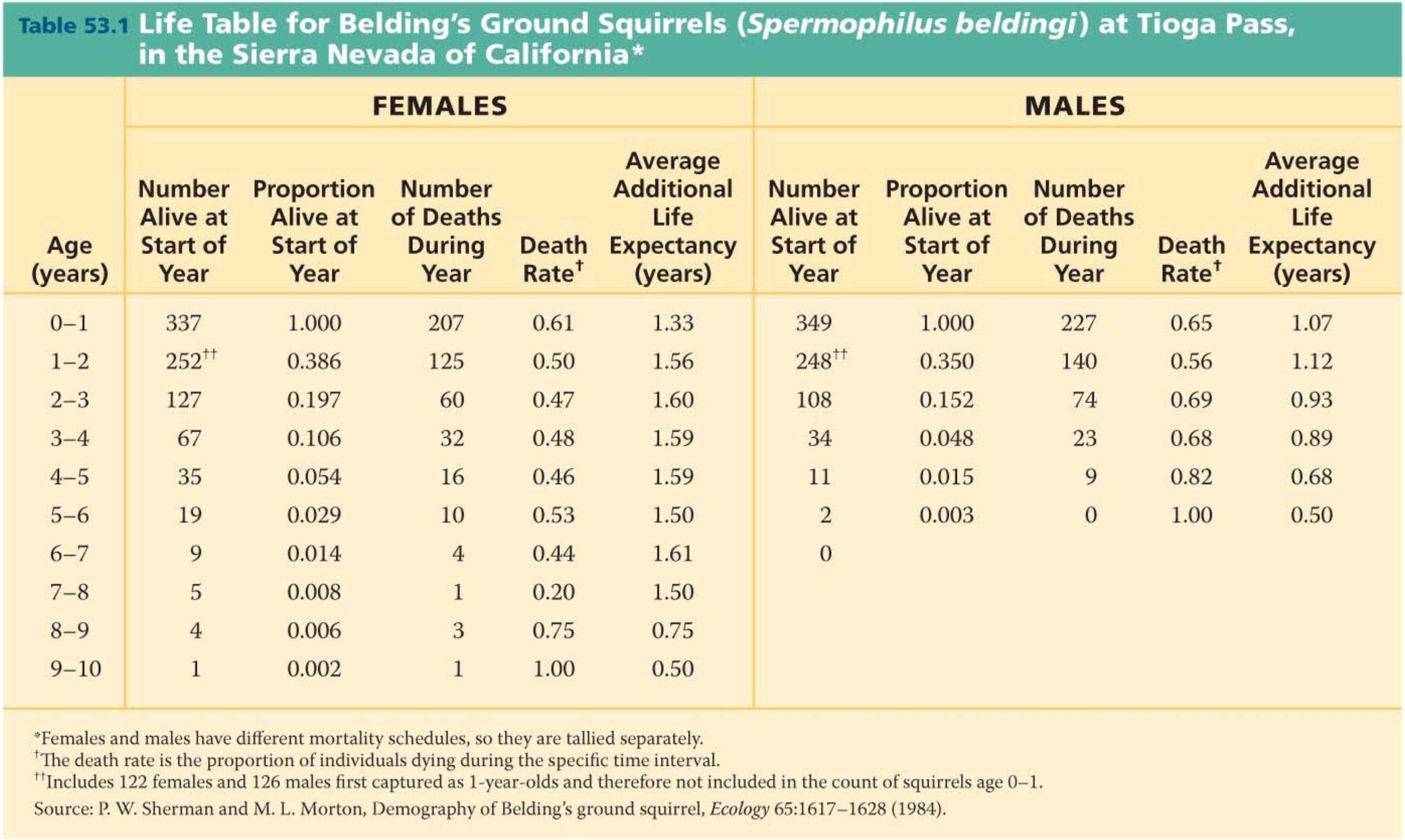


Table 53.1 **Life Table for Belding's Ground Squirrels (*Spermophilus beldingi*) at Tioga Pass, in the Sierra Nevada of California[*]**

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	0	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					

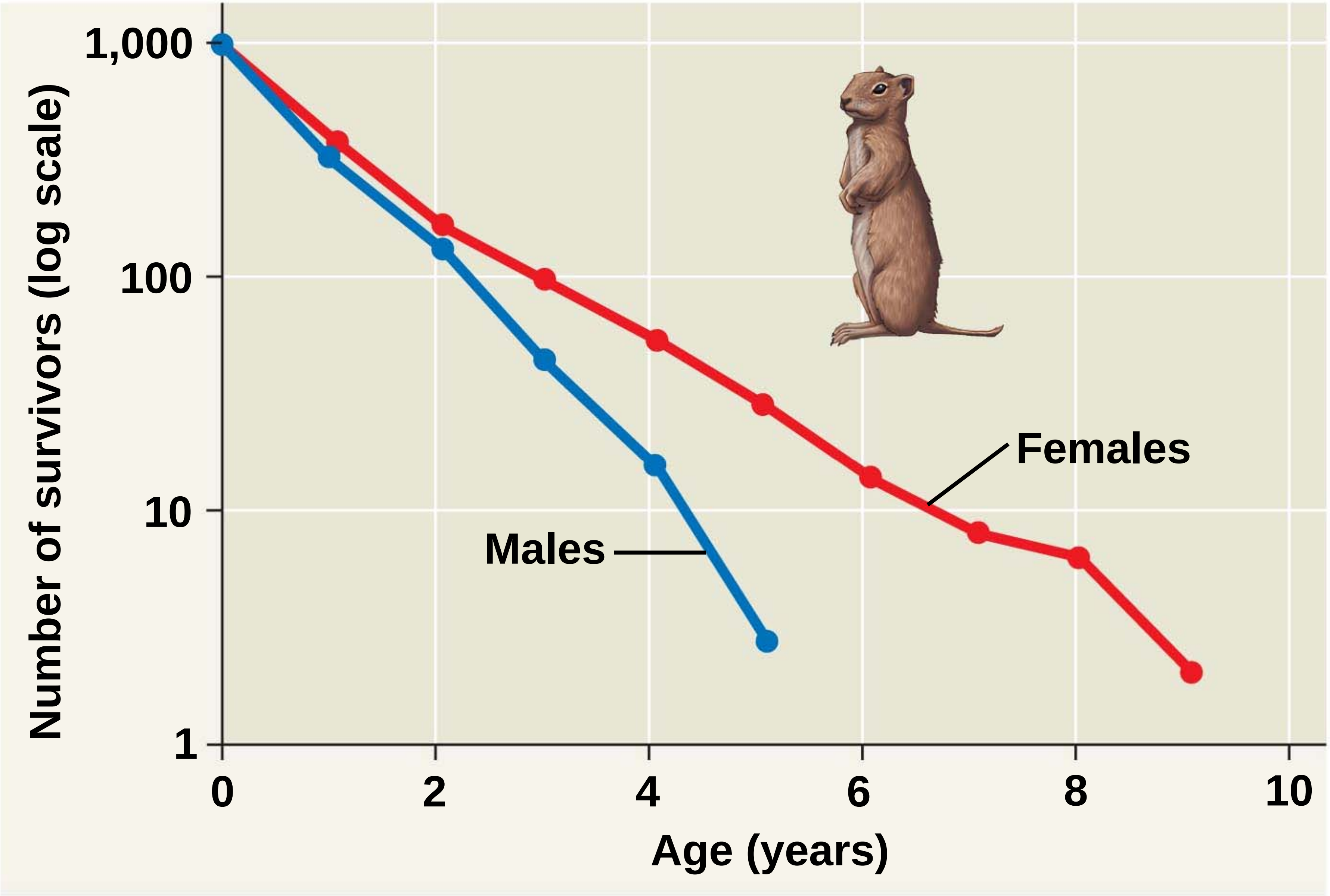
[*] Females and males have different mortality schedules, so they are tallied separately.
[†] The death rate is the proportion of individuals dying during the specific time interval.
[††] Includes 122 females and 126 males first captured as 1-year-olds and therefore not included in the count of squirrels age 0–1.

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

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

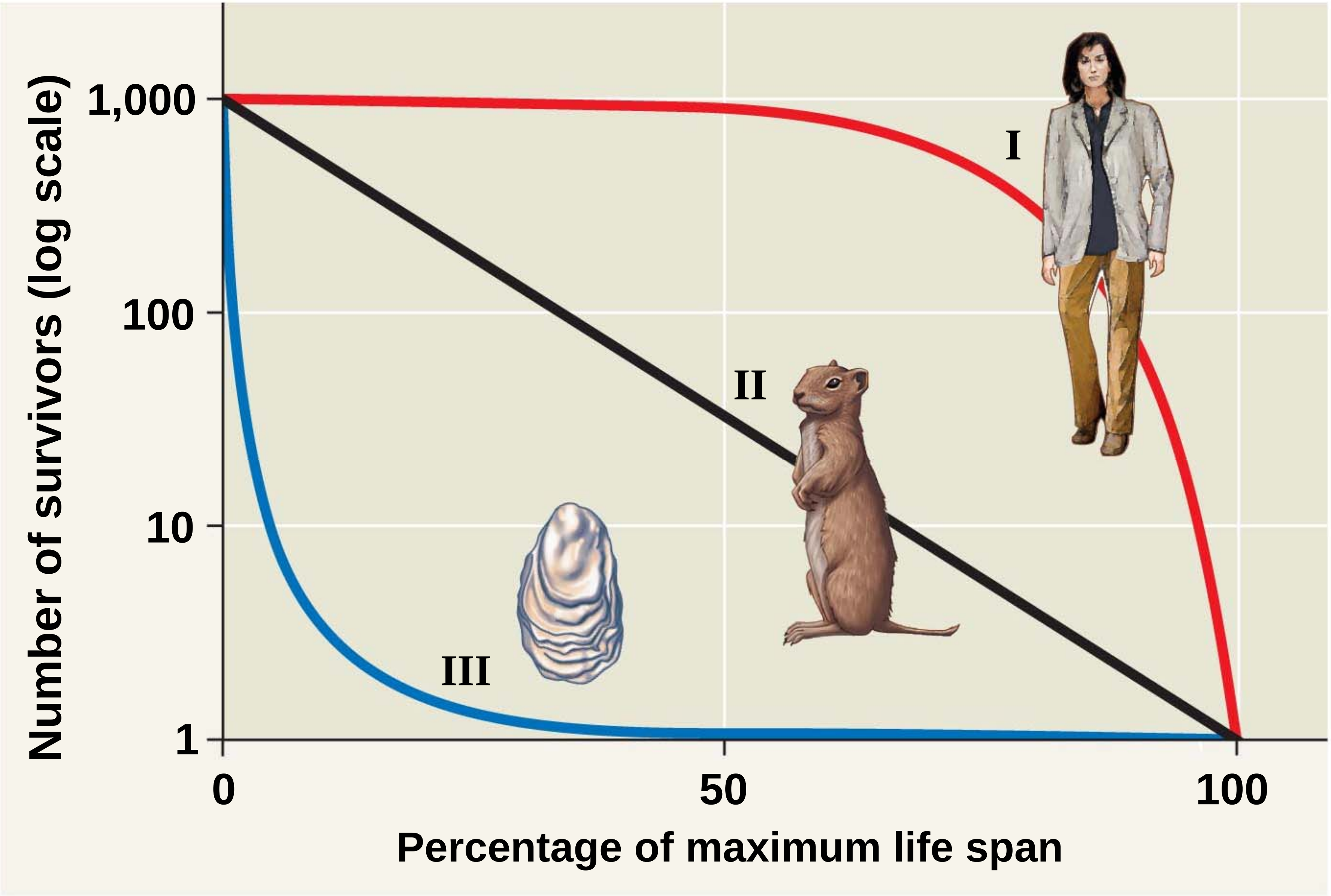
Fig. 53-5



1,000
100
10
1
Number of survivors (log scale)
0
2
4
6
8
10
Age (years)
Females
Males

- Survivorship curves can be classified into three general types:
  - Type I: low death rates during early and middle life, then an increase among older age groups
  - Type II: the death rate is constant over the organism's life span
  - Type III: high death rates for the young, then a slower death rate for survivors

Fig. 53-6



Number of survivors (log scale)
1,000
100
10
1
0
50
100
Percentage of maximum life span
I
II
III

Reproductive Rates

- For species with sexual reproduction, demographers often concentrate on females in a population
- A **reproductive table**, or fertility schedule, is an age-specific summary of the reproductive rates in a population
- It describes reproductive patterns of a population

Table 53-2

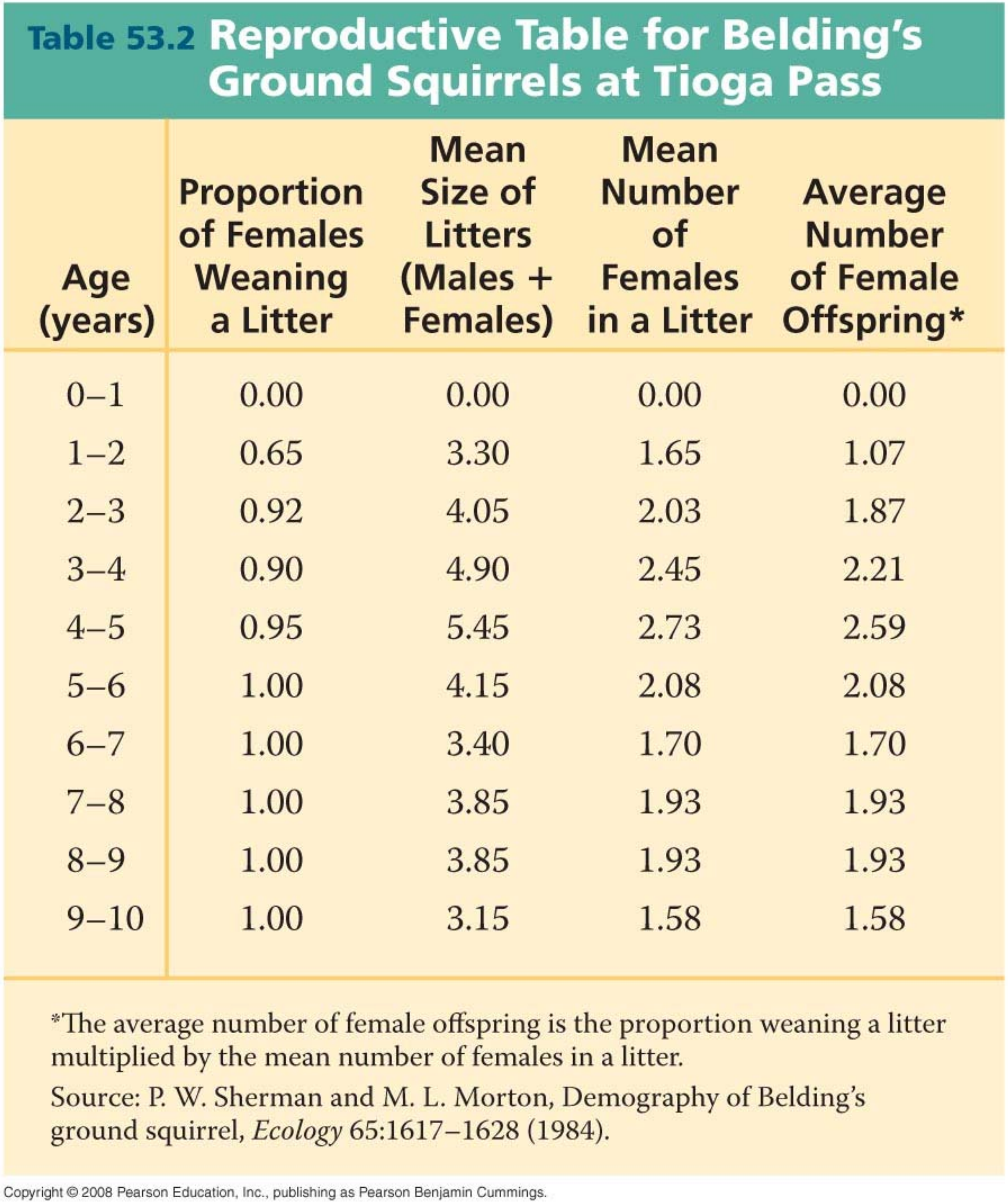


Table 53.2 **Reproductive Table for Belding's Ground Squirrels at Tioga Pass**

Age (years)	Proportion of Females Weaning a Litter	Mean Size of Litters (Males + Females)	Mean Number of Females in a Litter	Average Number of Female Offspring*
0–1	0.00	0.00	0.00	0.00
1–2	0.65	3.30	1.65	1.07
2–3	0.92	4.05	2.03	1.87
3–4	0.90	4.90	2.45	2.21
4–5	0.95	5.45	2.73	2.59
5–6	1.00	4.15	2.08	2.08
6–7	1.00	3.40	1.70	1.70
7–8	1.00	3.85	1.93	1.93
8–9	1.00	3.85	1.93	1.93
9–10	1.00	3.15	1.58	1.58

*The average number of female offspring is the proportion weaning a litter multiplied by the mean number of females in a litter.

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

Concept 53.2: 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

- Life histories are very diverse
- 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

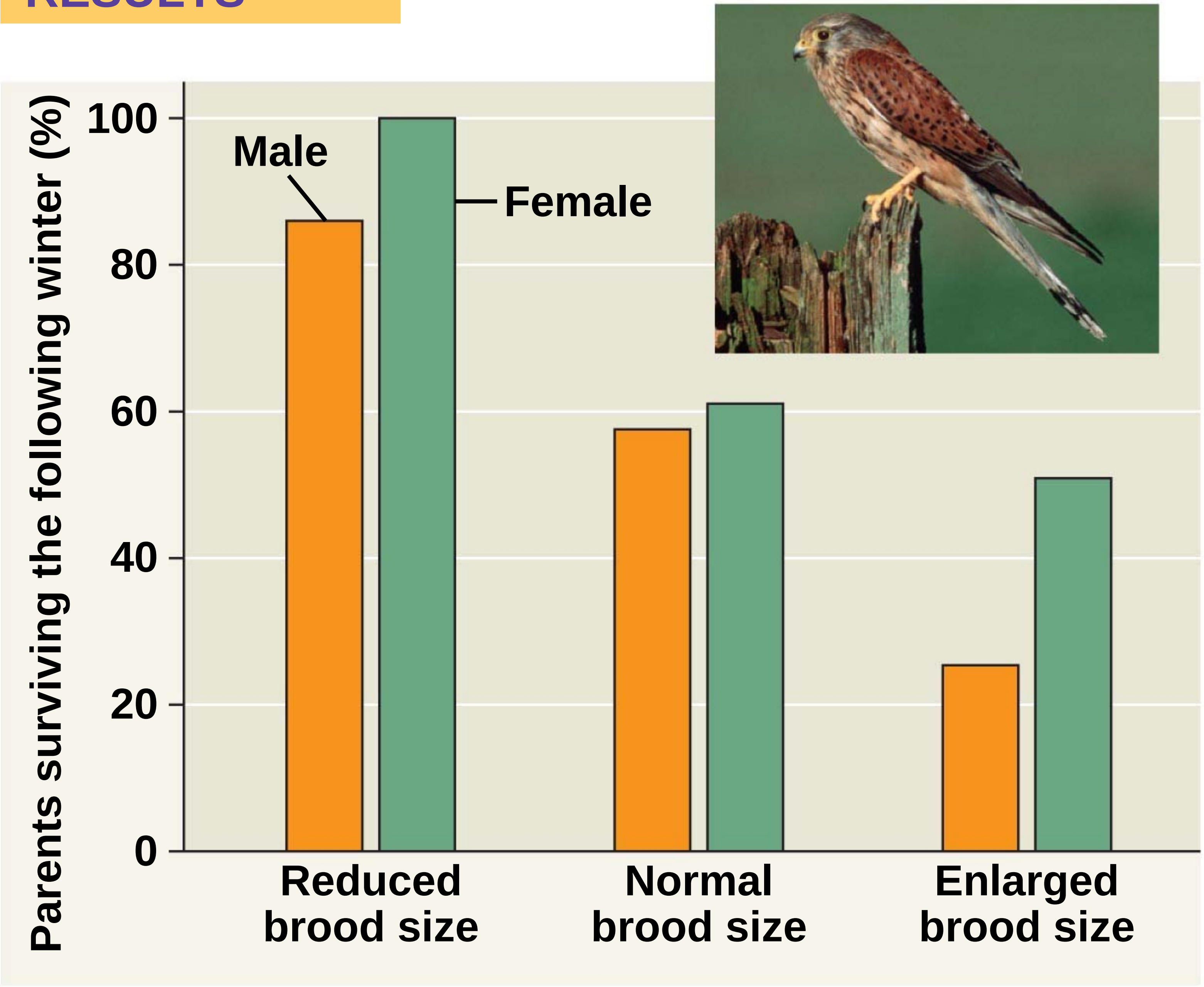
Fig. 53-7

“Trade-offs” and Life Histories

- Organisms have finite resources, which may lead to trade-offs between survival and reproduction

Fig. 53-8

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) Coconut palm

(a) Dandelion

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

Fig. 53-9b

(b) Coconut palm

- In animals, parental care of smaller broods may facilitate survival of offspring

Concept 53.3: 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

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

- **Zero population growth** occurs when the birth rate equals the death rate
- Most ecologists use differential calculus to express population growth as growth rate at a particular instant in time:

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

where N = population size, t = time, and r = per capita rate of increase = birth – death

Exponential Growth

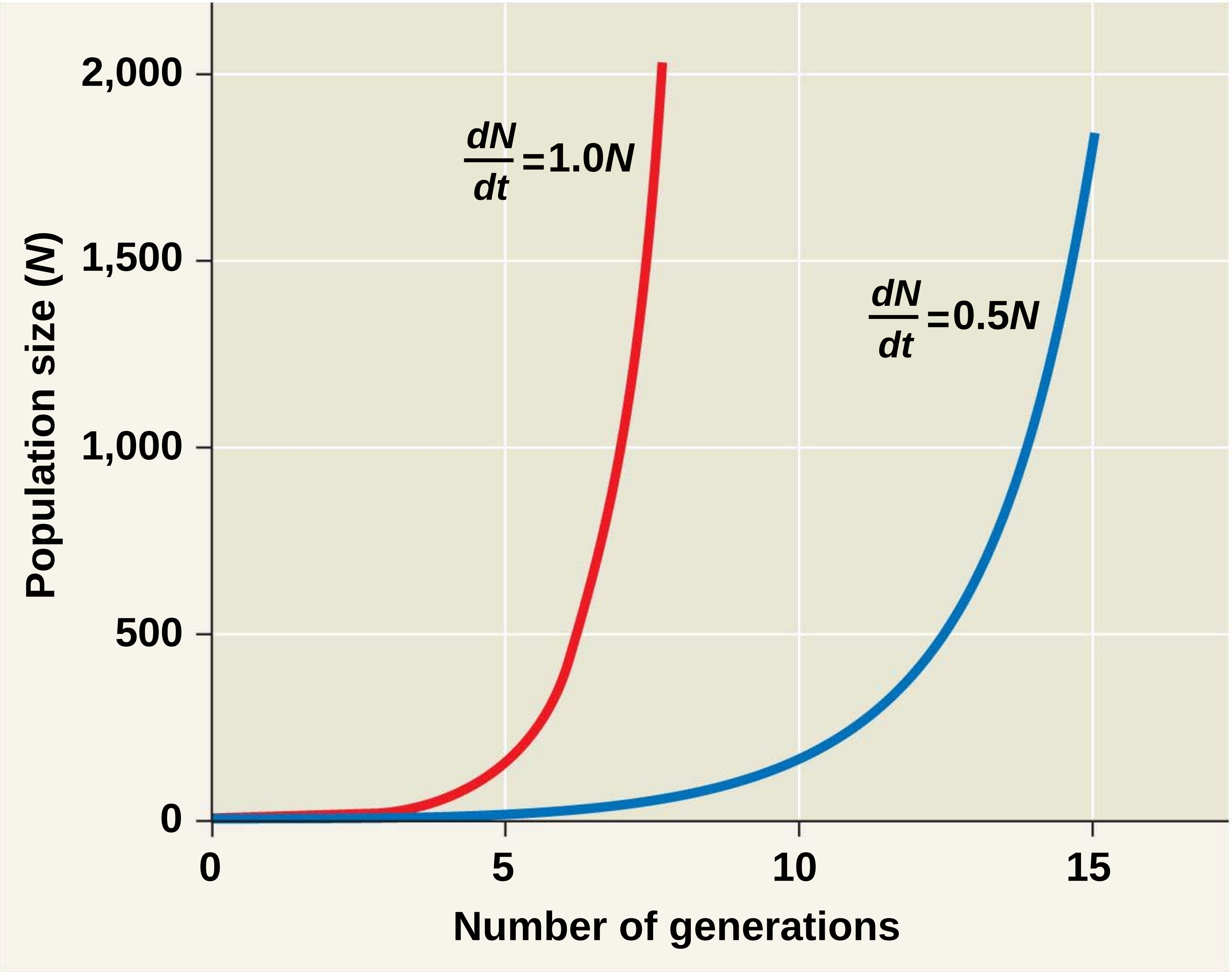
- **Exponential population growth** is population increase under idealized conditions
- Under these conditions, the rate of reproduction is at its maximum, called the intrinsic rate of increase

- Equation of exponential population growth:

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

- Exponential population growth results in a J-shaped curve

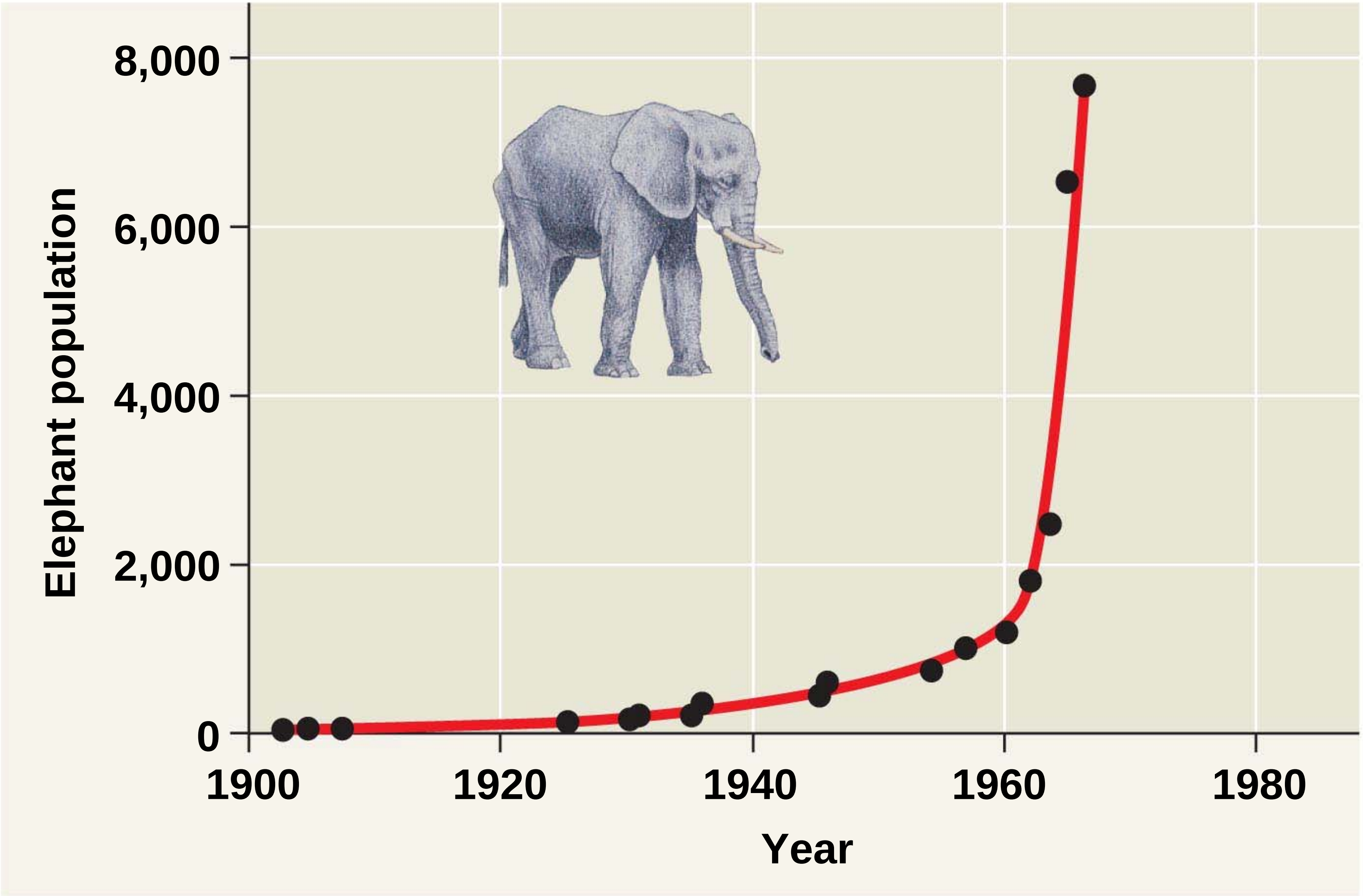
Fig. 53-10



2,000
1,500
1,000
500
0
Population size (N)
$\frac{dN}{dt} = 1.0N$
$\frac{dN}{dt} = 0.5N$
0
5
10
15
Number of generations

- The J-shaped curve of exponential growth characterizes some rebounding populations

Fig. 53-11



8,000
6,000
4,000
2,000
0
Elephant population
1900
1920
1940
1960
1980
Year

Concept 53.4: 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

The Logistic Growth Model

- In the **logistic population growth** model, the per capita rate of increase declines as carrying capacity is reached

- We construct the logistic model by starting with the exponential model and adding 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

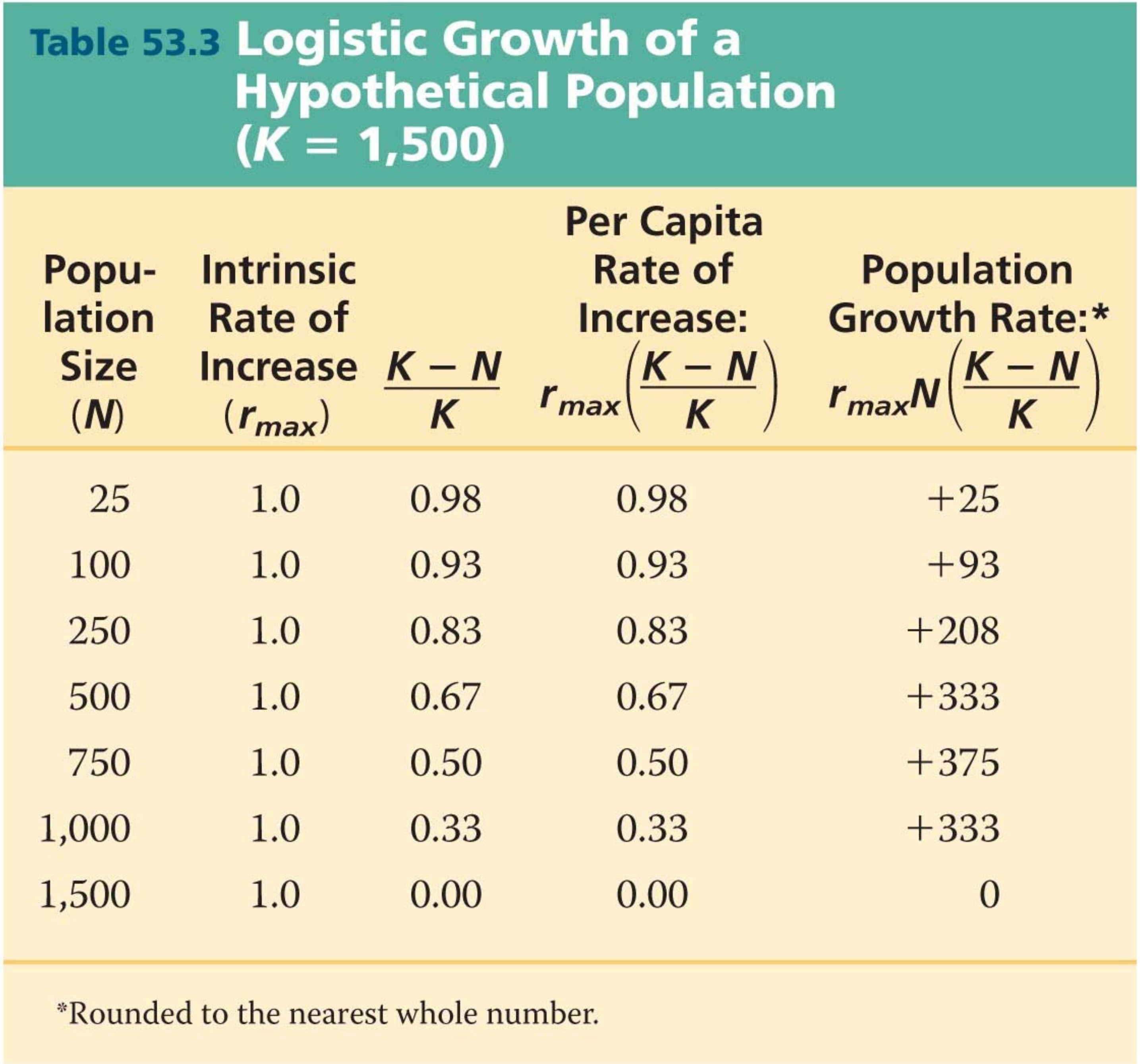


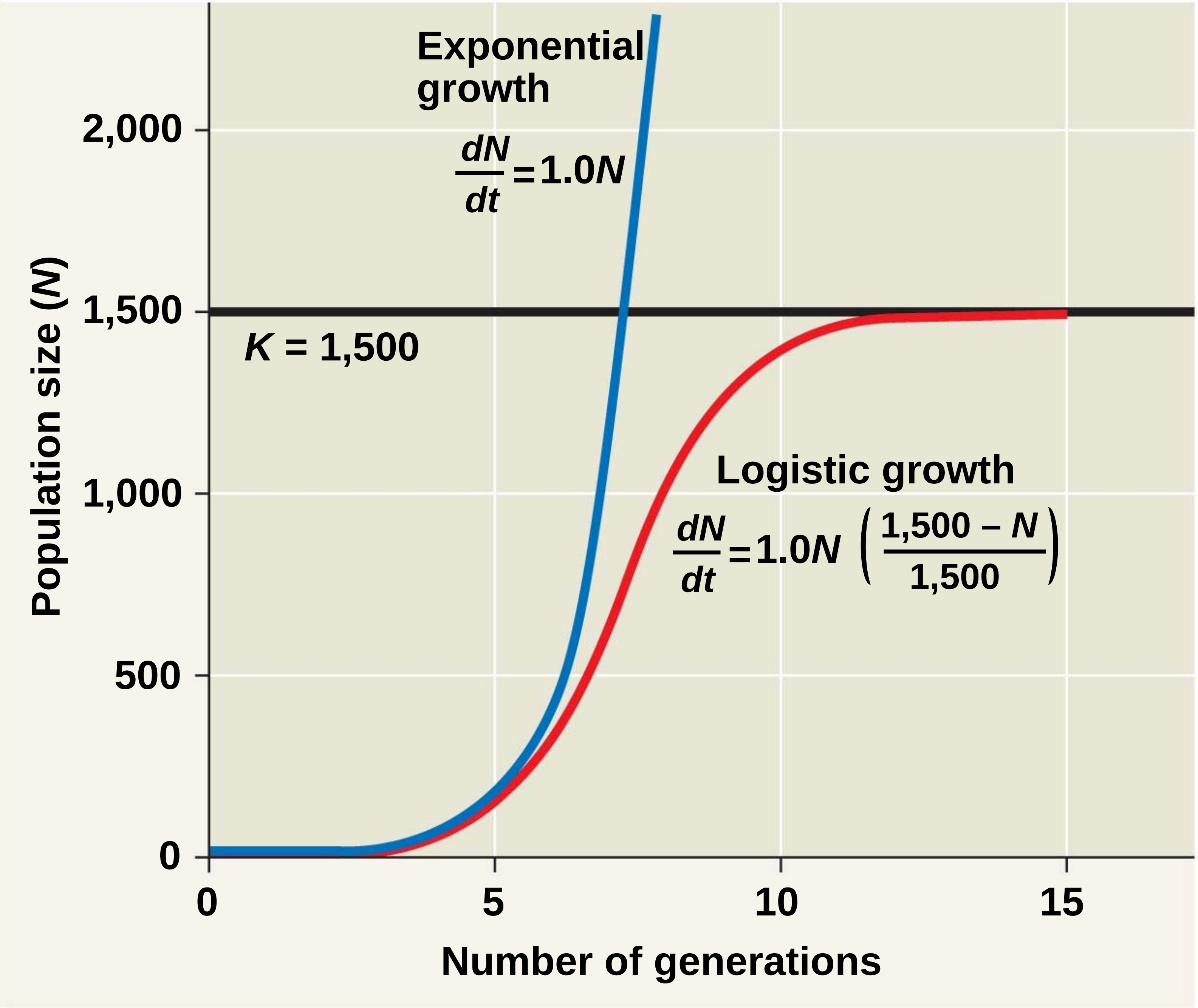
Table 53.3 Logistic Growth of a Hypothetical Population ($K = 1{,}500$)

Population Size (N)	Intrinsic 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

Fig. 53-12

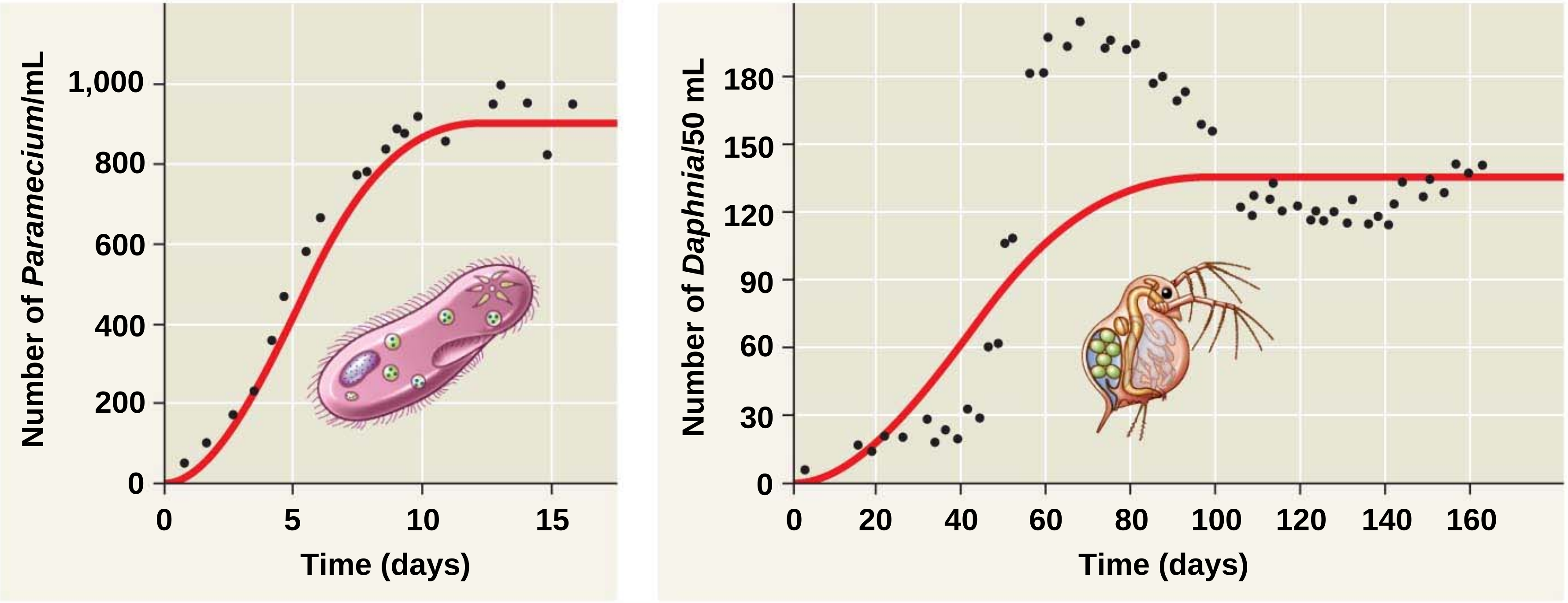


Exponential growth
$\frac{dN}{dt} = 1.0N$
Logistic growth
$\frac{dN}{dt} = 1.0N\left(\frac{1{,}500 - N}{1{,}500}\right)$
K = 1,500
Population size (N)
2,000
1,500
1,000
500
0
0
5
10
15
Number of generations

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

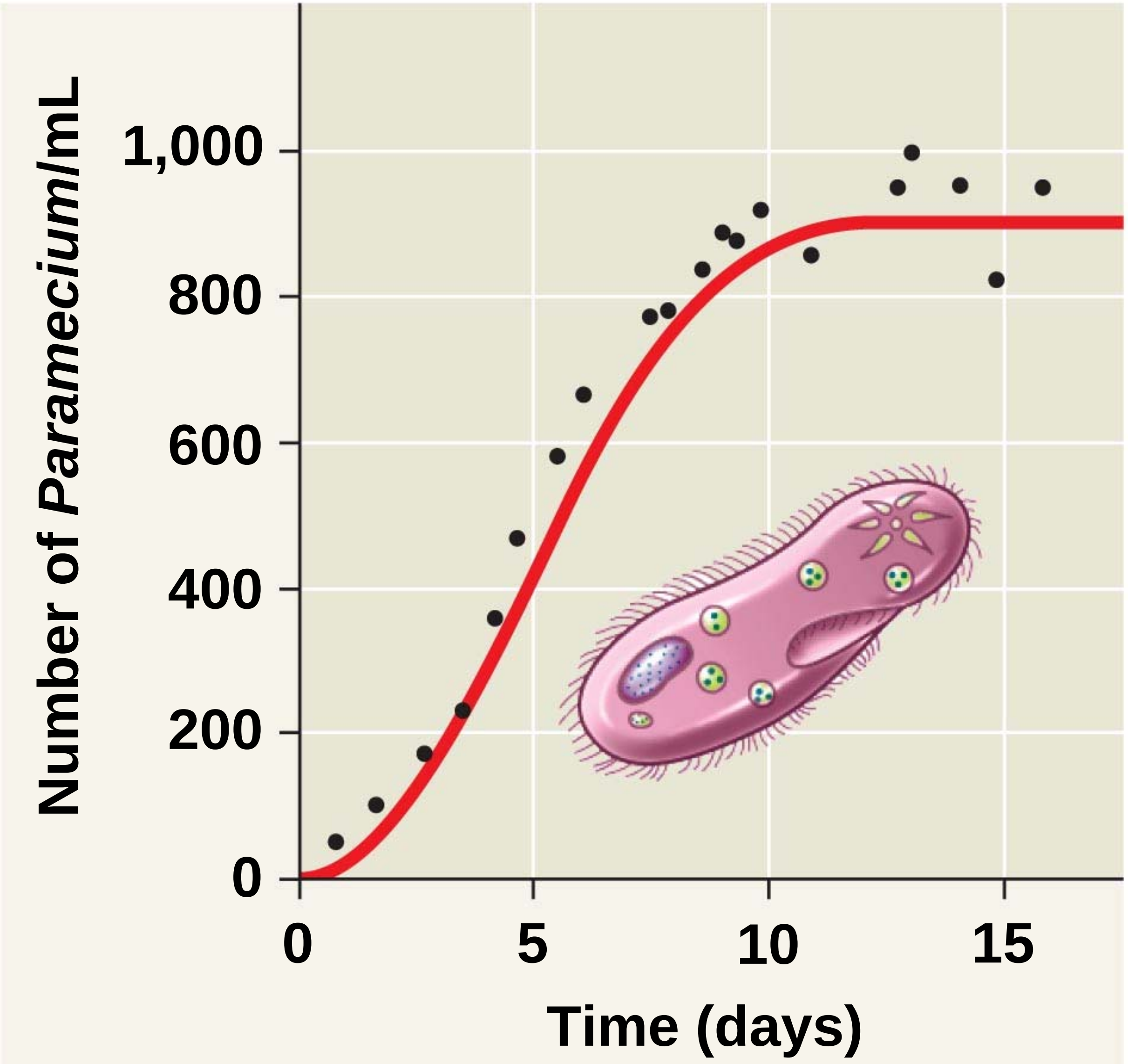
Fig. 53-13



(a) A *Paramecium* population in the lab

(b) A *Daphnia* population in the lab

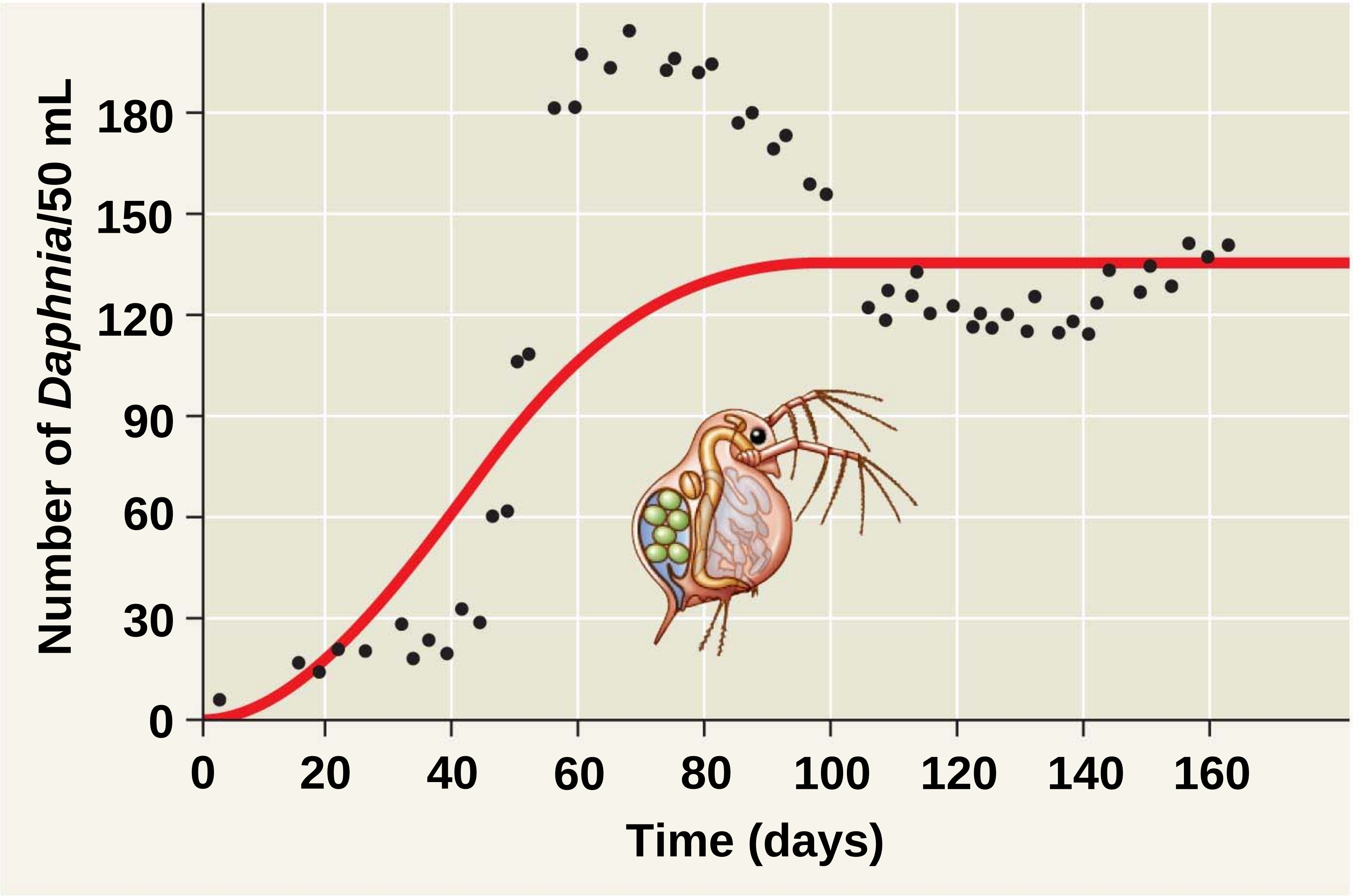
Fig. 53-13a



(a) A *Paramecium* population in the lab

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

Fig. 53-13b



(b) A *Daphnia* population in the lab

- 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

Fig. 53-14

The Logistic Model and Life Histories

- Life history traits favored by natural selection may vary with population density and environmental conditions
- ***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

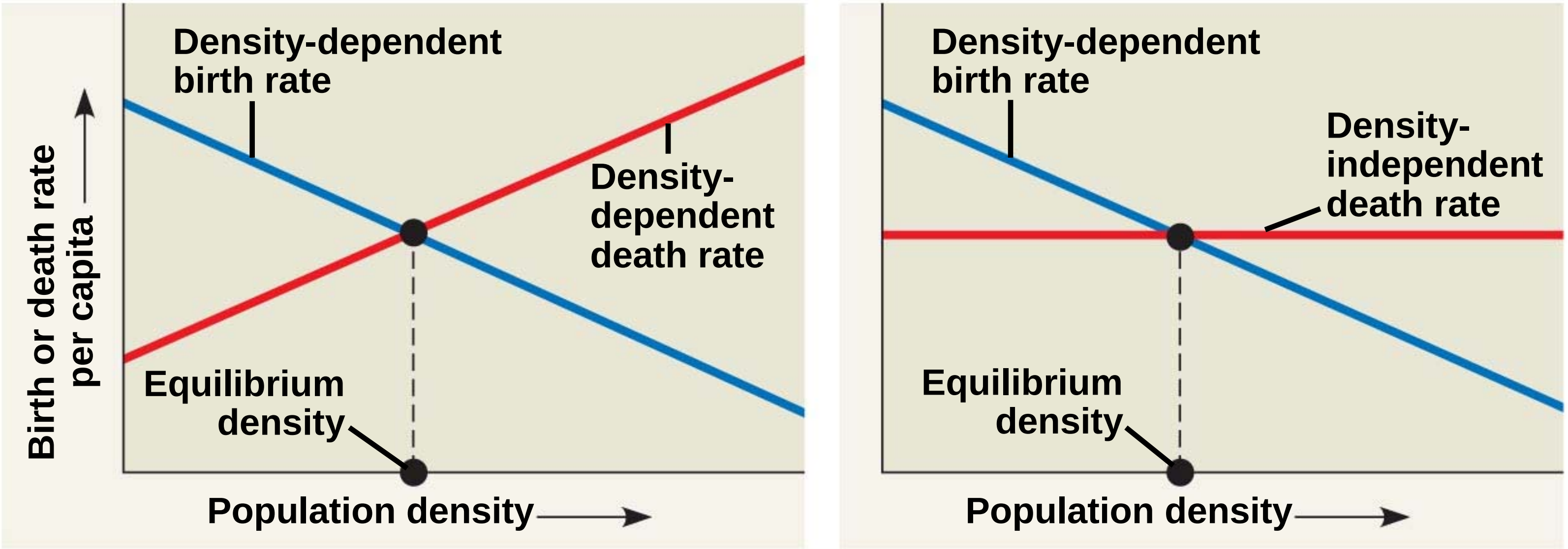
Concept 53.5: Many factors that regulate population growth are density dependent

- 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

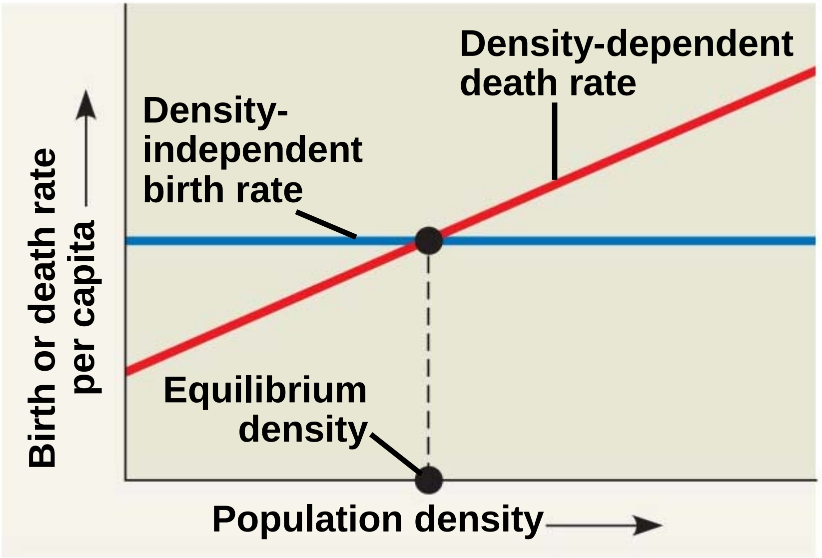
- In **density-independent** populations, birth rate and death rate do not change with population density
- In **density-dependent** populations, birth rates fall and death rates rise with population density

Fig. 53-15



(a) Both birth rate and death rate vary.

(b) Birth rate varies; death rate is constant.



(c) Death rate varies; birth rate is constant.

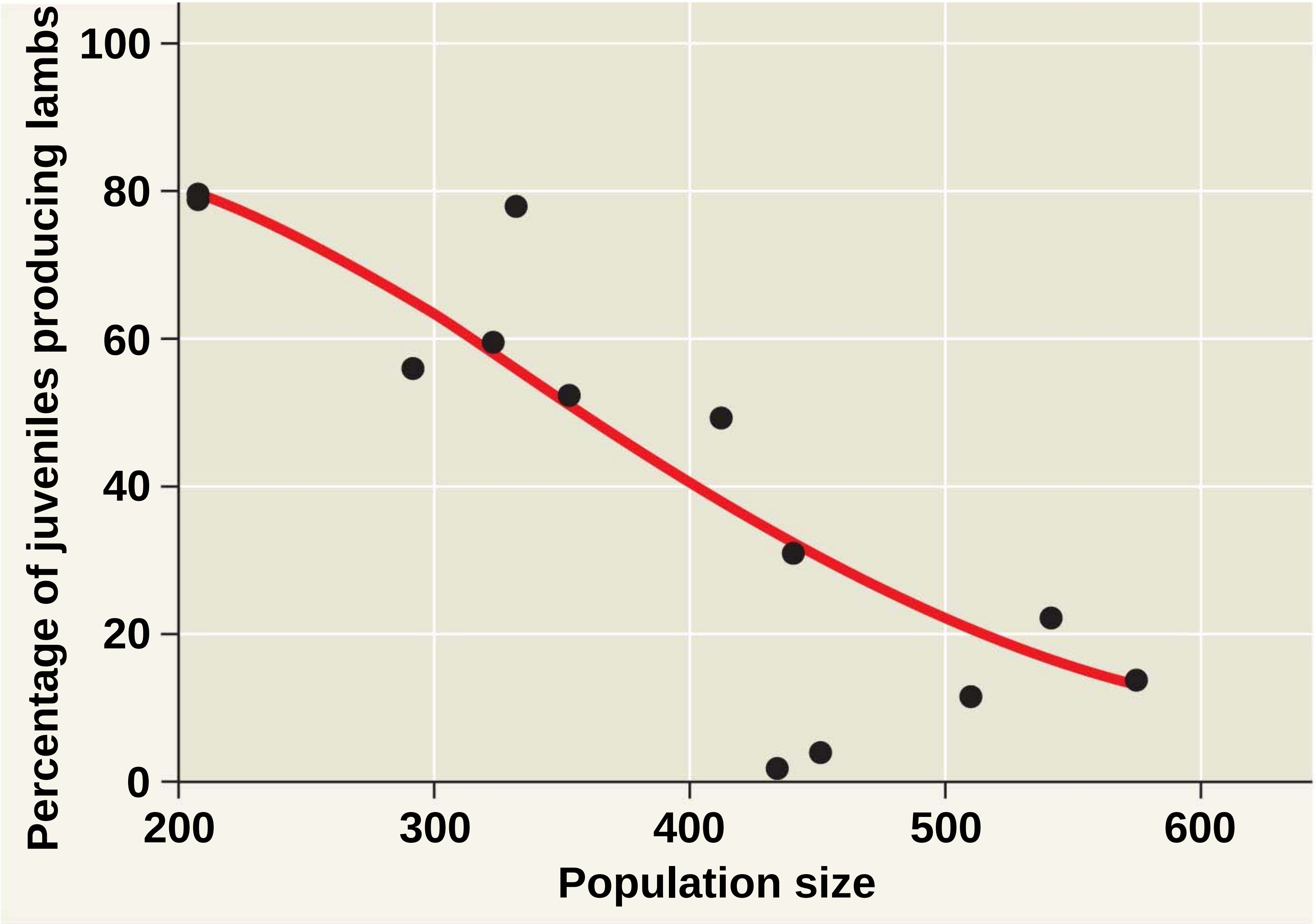
Density-Dependent Population Regulation

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

Competition for Resources

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

Fig. 53-16



Percentage of juveniles producing lambs
100
80
60
40
20
0
200
300
400
500
600
Population size

Territoriality

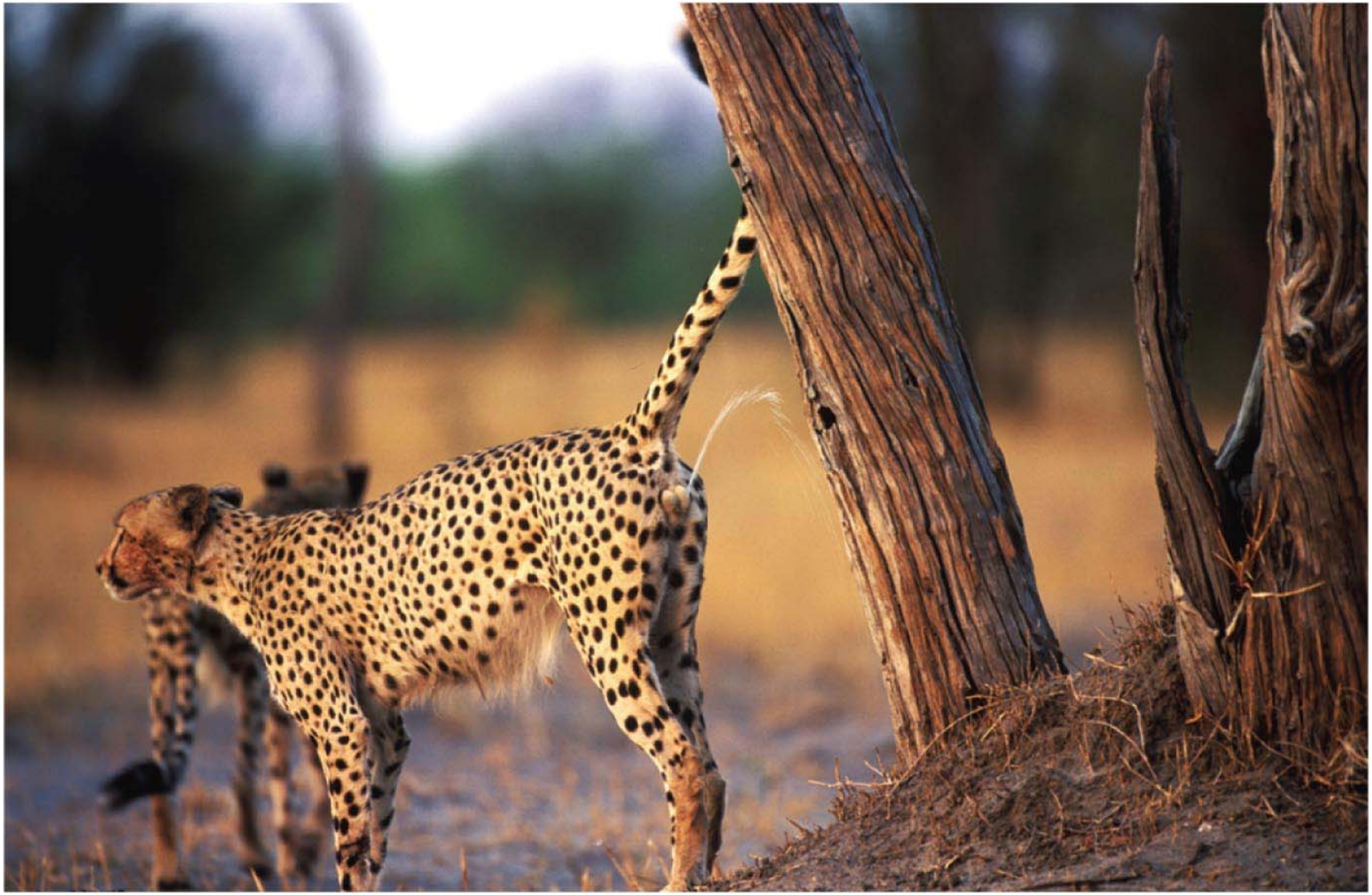
- In many vertebrates and some invertebrates, competition for territory may limit density
- Cheetahs are highly territorial, using chemical communication to warn other cheetahs of their boundaries

Fig. 53-17

(a) Cheetah marking its territory

(b) Gannets

Fig. 53-17a



(a) Cheetah marking its territory

- Oceanic birds exhibit territoriality in nesting behavior

Fig. 53-17b

(b) Gannets

Disease

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

Predation

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

Toxic Wastes

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

Intrinsic Factors

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

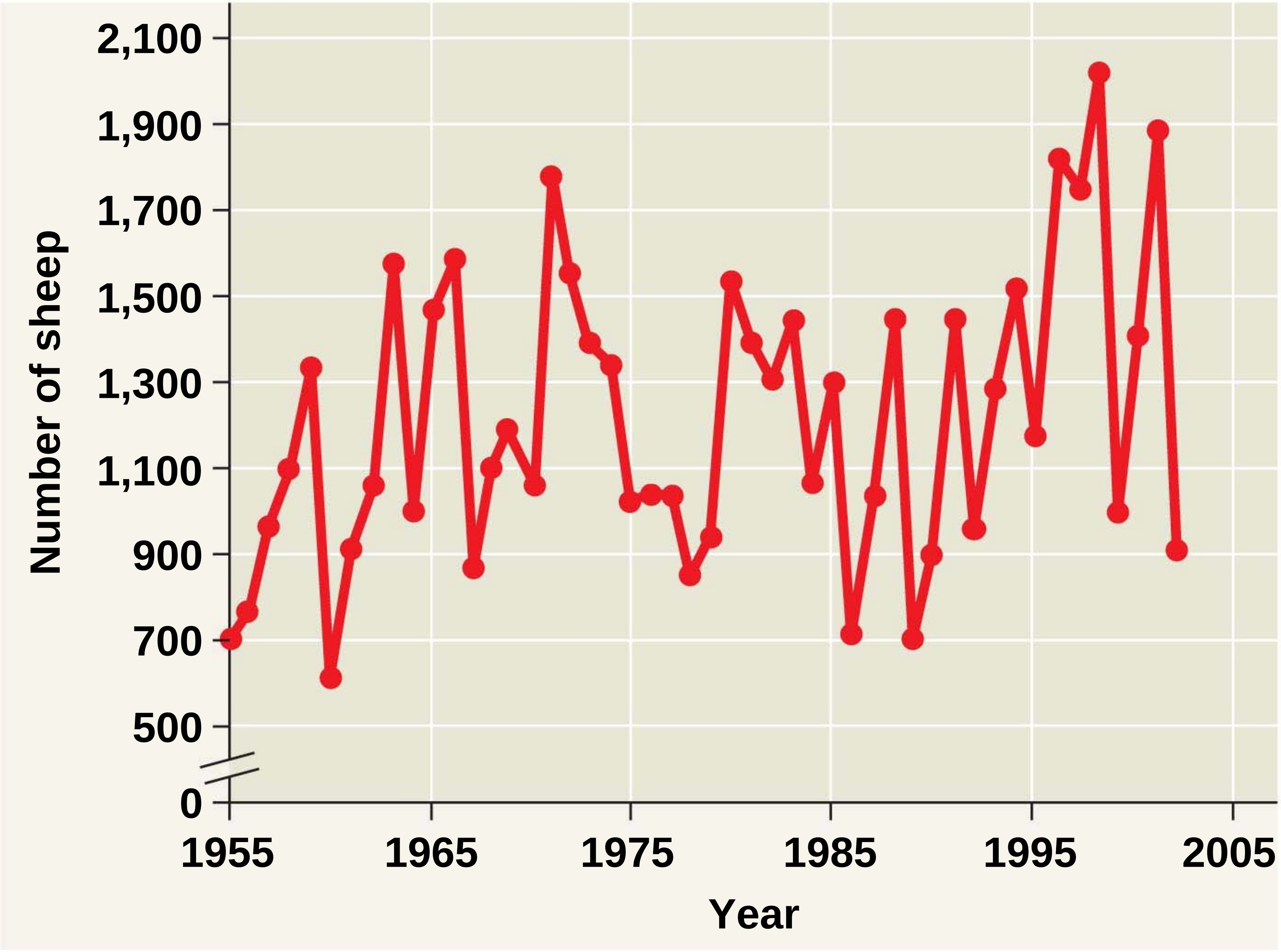
Population Dynamics

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

Stability and Fluctuation

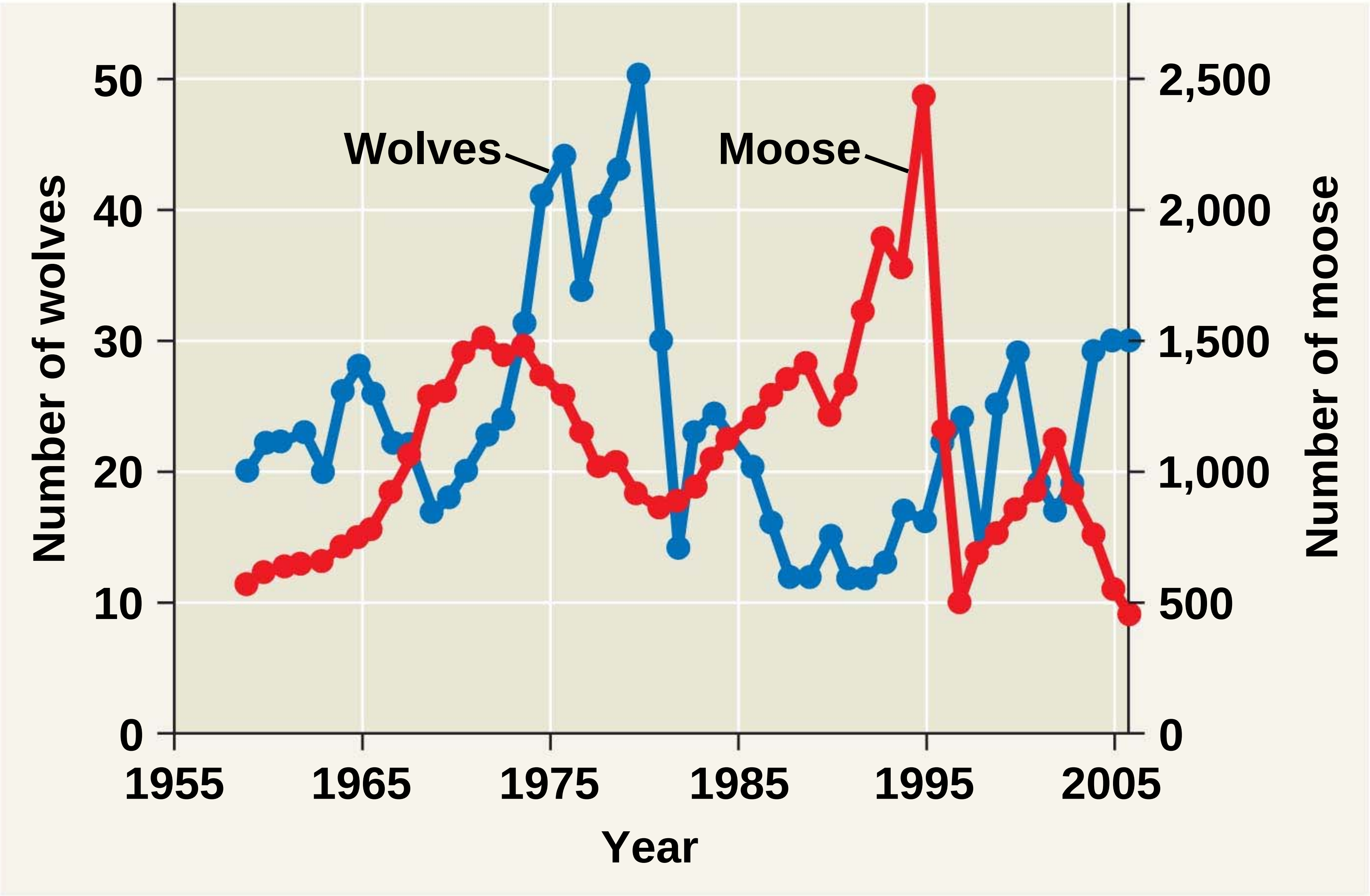
- Long-term population studies have challenged the hypothesis that populations of large mammals are relatively stable over time
- Weather can affect population size over time

Fig. 53-18


Number of sheep
2,100
1,900
1,700
1,500
1,300
1,100
900
700
500
0
1955
1965
1975
1985
1995
2005
Year

- Changes in predation pressure can drive population fluctuations

Fig. 53-19



Wolves
Moose
Number of wolves
Number of moose
50
40
30
20
10
0
2,500
2,000
1,500
1,000
500
0
1955
1965
1975
1985
1995
2005
Year

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

Fig. 53-20

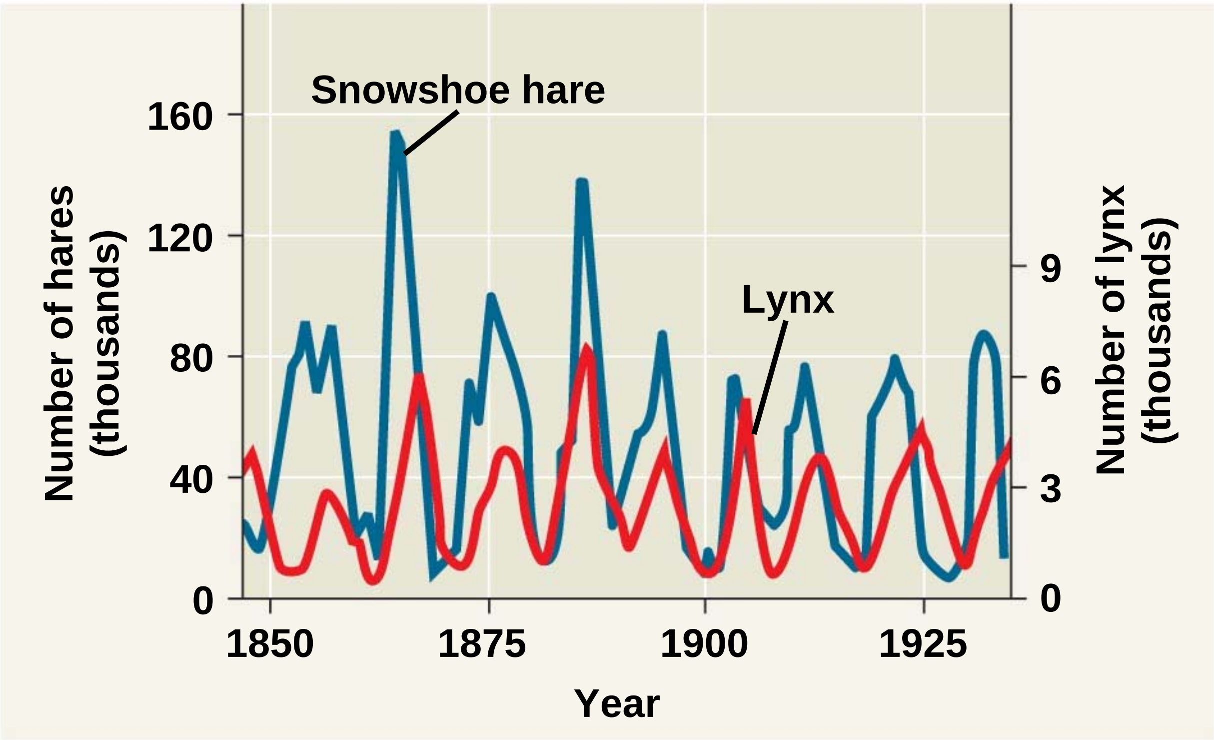
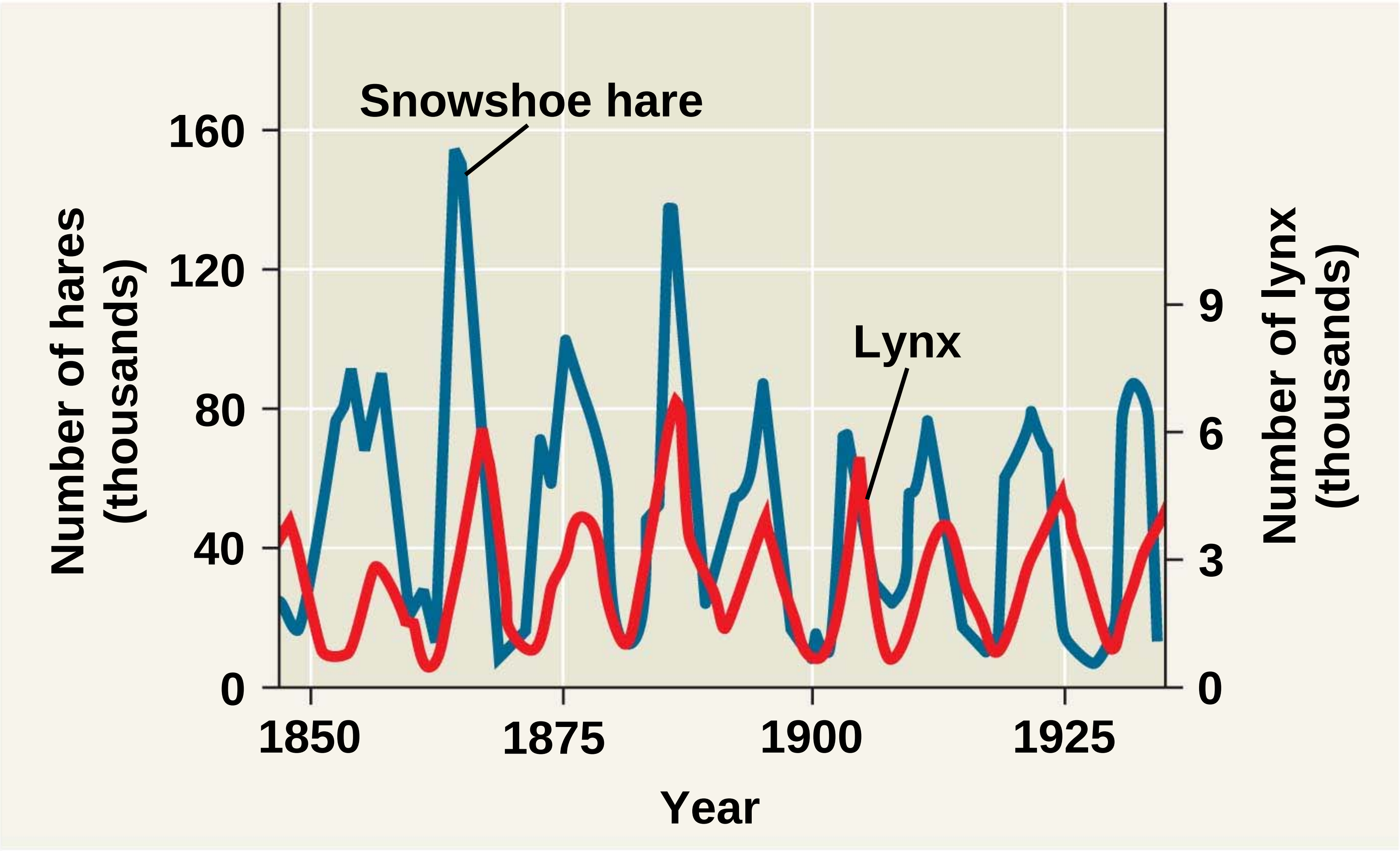

Snowshoe hare
Lynx
Number of hares (thousands)
160
120
80
40
0
Number of lynx (thousands)
9
6
3
0
1850
1875
1900
1925
Year

Fig. 53-20a

Fig. 53-20b


Snowshoe hare
Lynx
Number of hares (thousands)
160
120
80
40
0
Number of lynx (thousands)
9
6
3
0
1850
1875
1900
1925
Year

- 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
- No hares appeared to have died of starvation

- 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 this second hypothesis

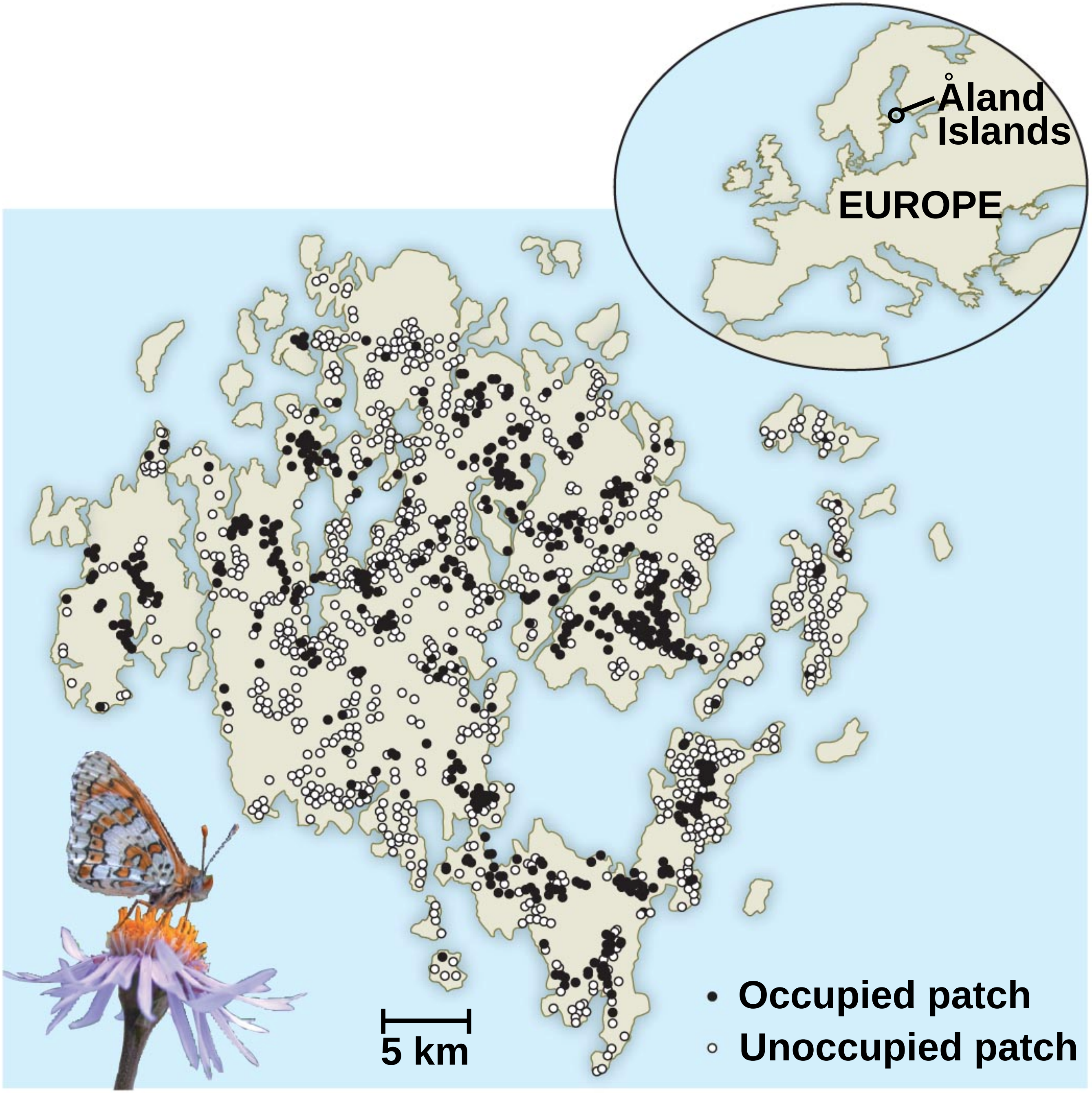
- Hypothesis: The hare’s population cycle is linked to sunspot cycles
- Sunspot activity affects light quality, which in turn affects the quality of the hares’ food
- There is good correlation between sunspot activity and hare population size

- 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

Immigration, Emigration, and Metapopulations

- **Metapopulations** are groups of populations linked by immigration and emigration
- High levels of immigration combined with higher survival can result in greater stability in populations

Fig. 53-21



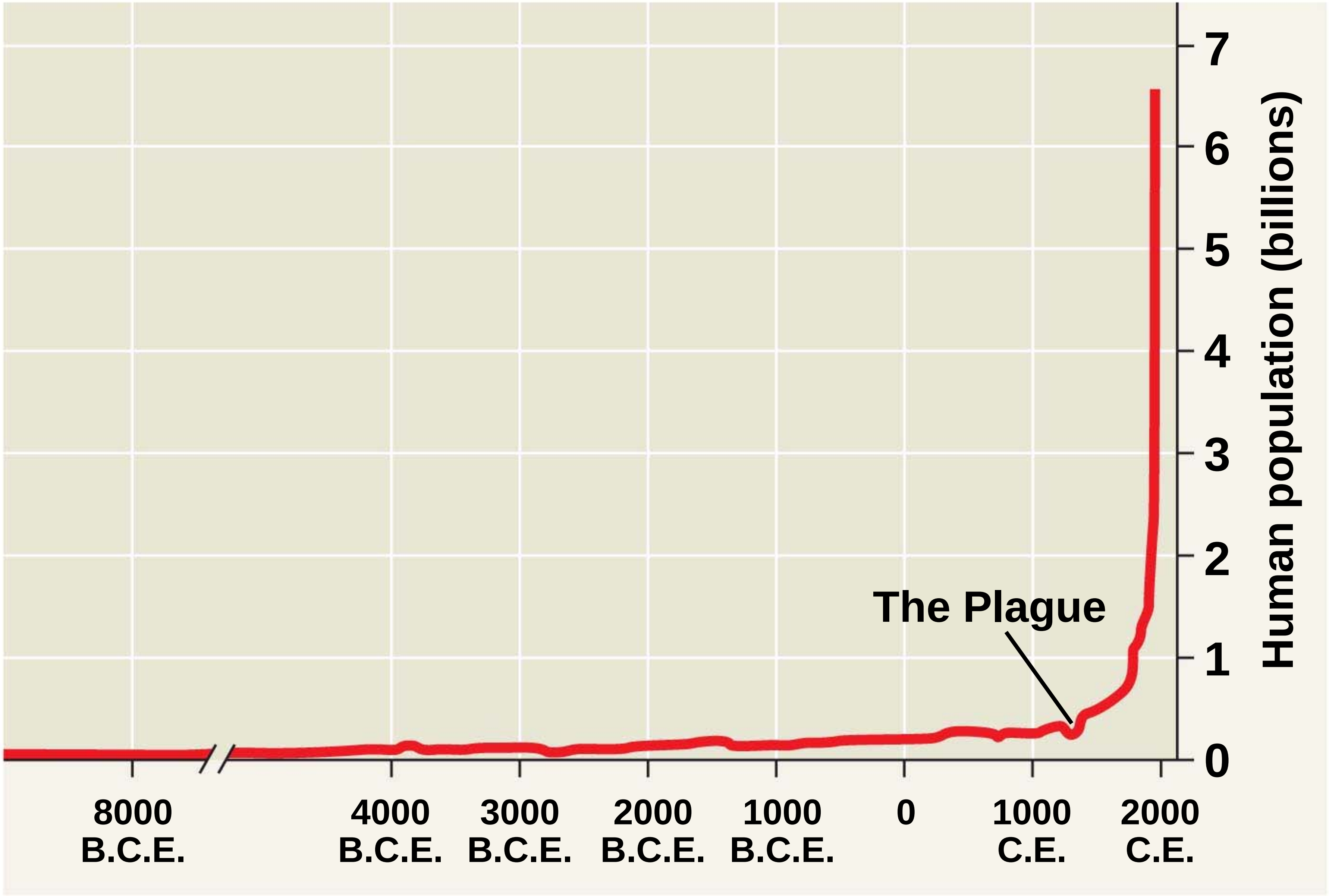
Concept 53.6: The human population is no longer growing exponentially but is still increasing rapidly

- 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

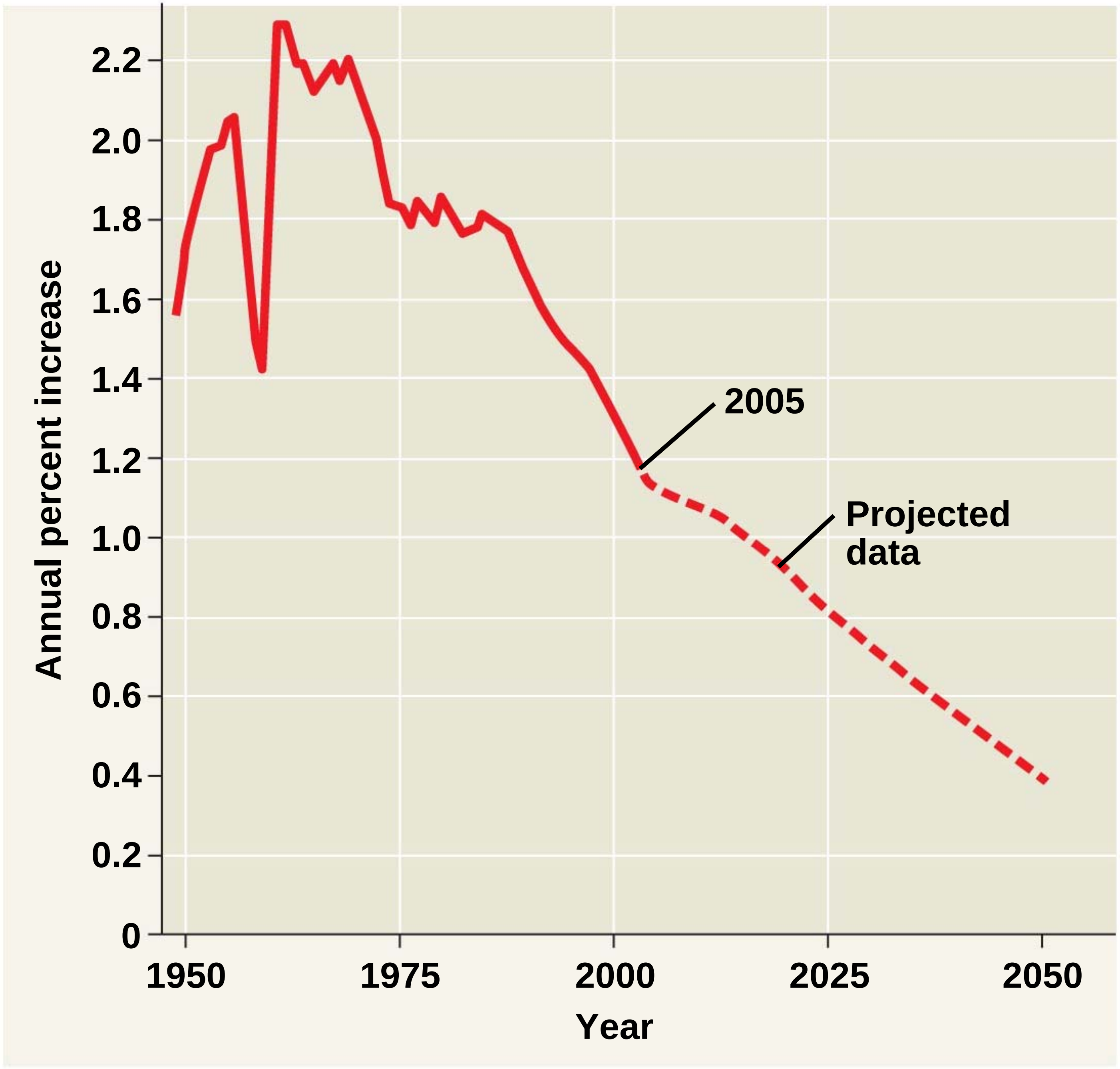
Fig. 53-22



7
6
5
4
3
2
1
0
Human population (billions)
The Plague
8000 B.C.E.
4000 B.C.E.
3000 B.C.E.
2000 B.C.E.
1000 B.C.E.
0
1000 C.E.
2000 C.E.

- Though the global population is still growing, the rate of growth began to slow during the 1960s

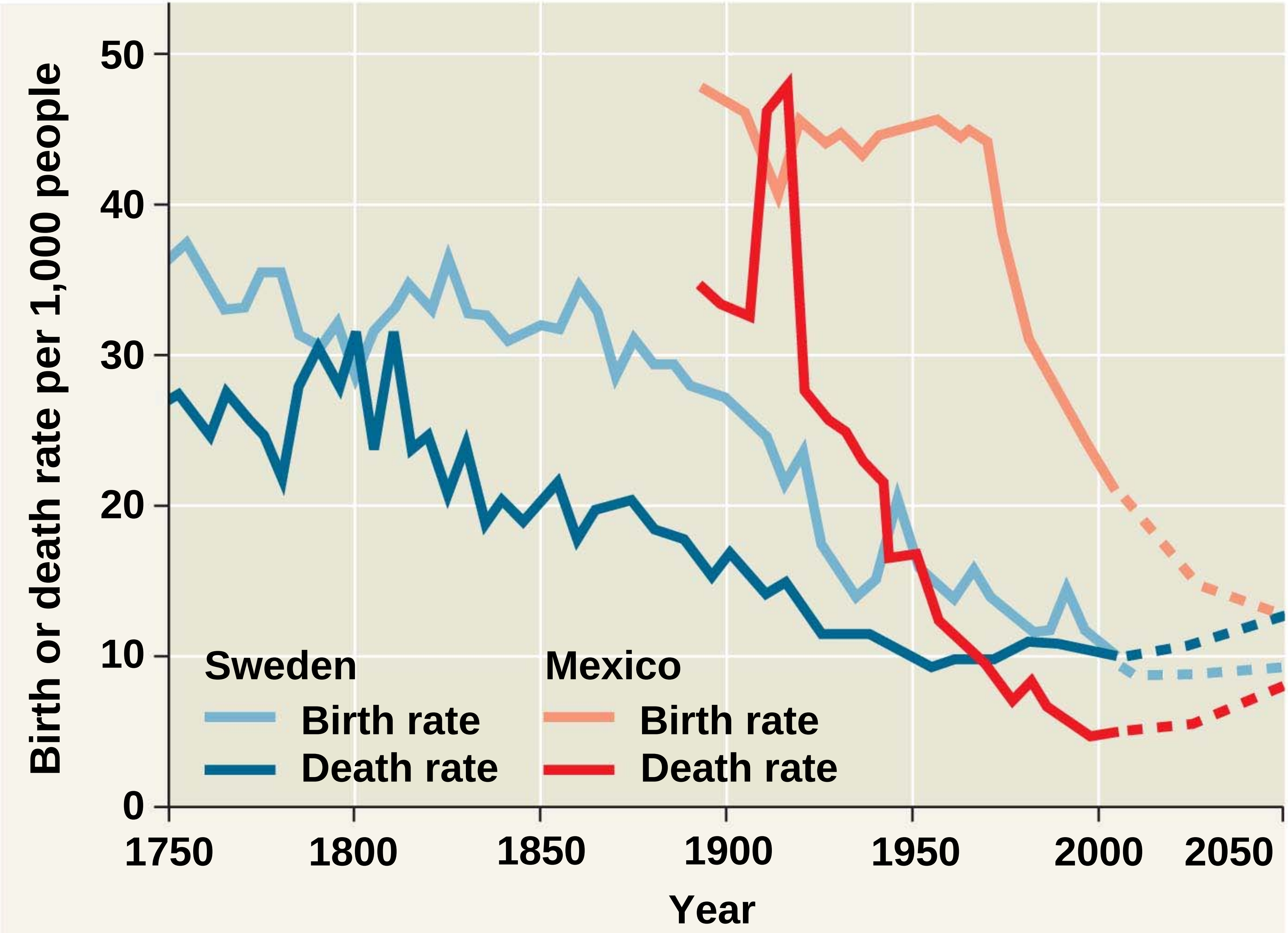
Fig. 53-23


2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Annual percent increase
1950
1975
2000
2025
2050
Year
2005
Projected
data

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 toward the second state

Fig. 53-24

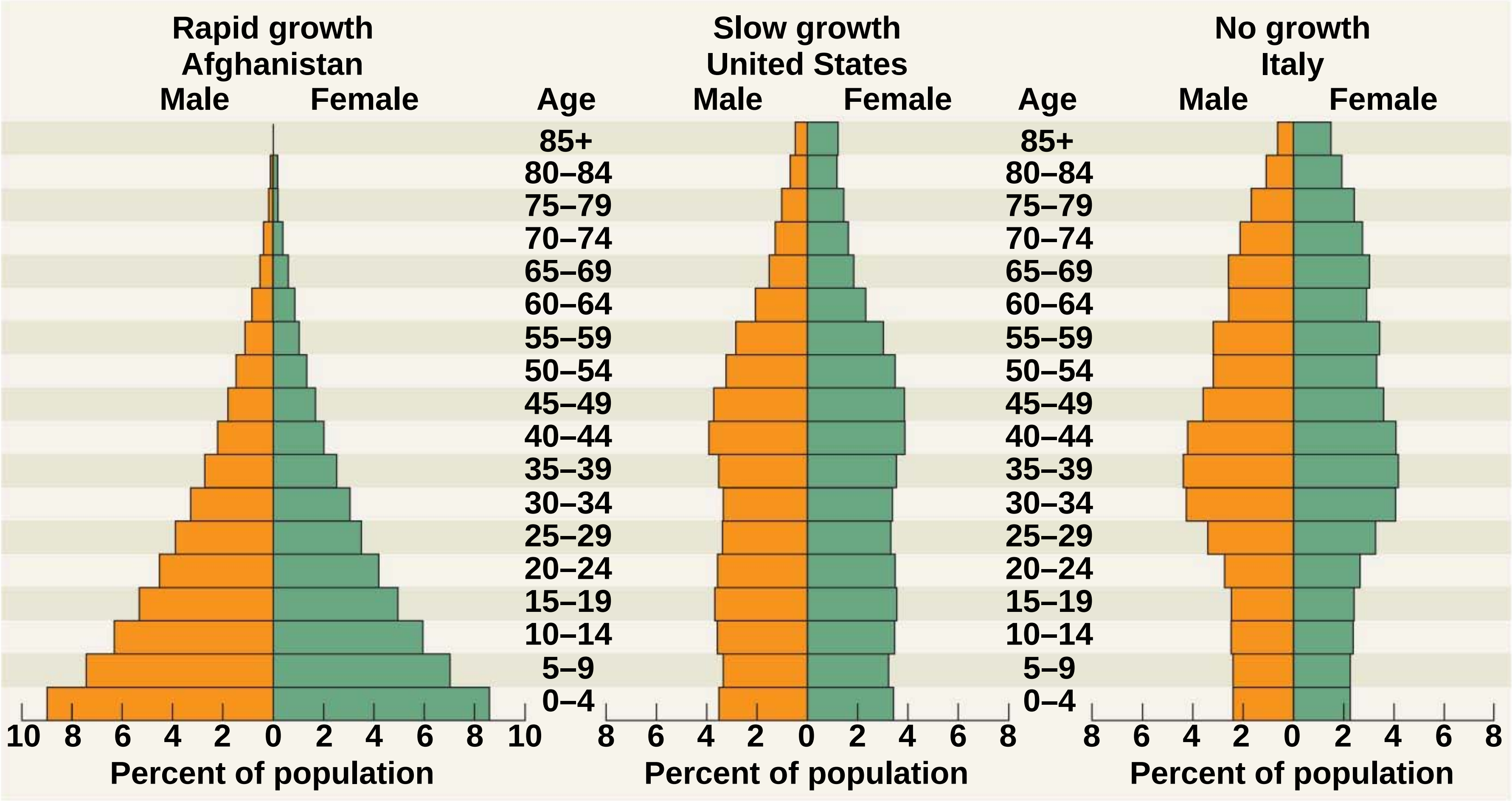

Birth or death rate per 1,000 people
50
40
30
20
10
0
1750
1800
1850
1900
1950
2000
2050
Year
Sweden
Birth rate
Death rate
Mexico
Birth rate
Death rate

- 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

Fig. 53-25



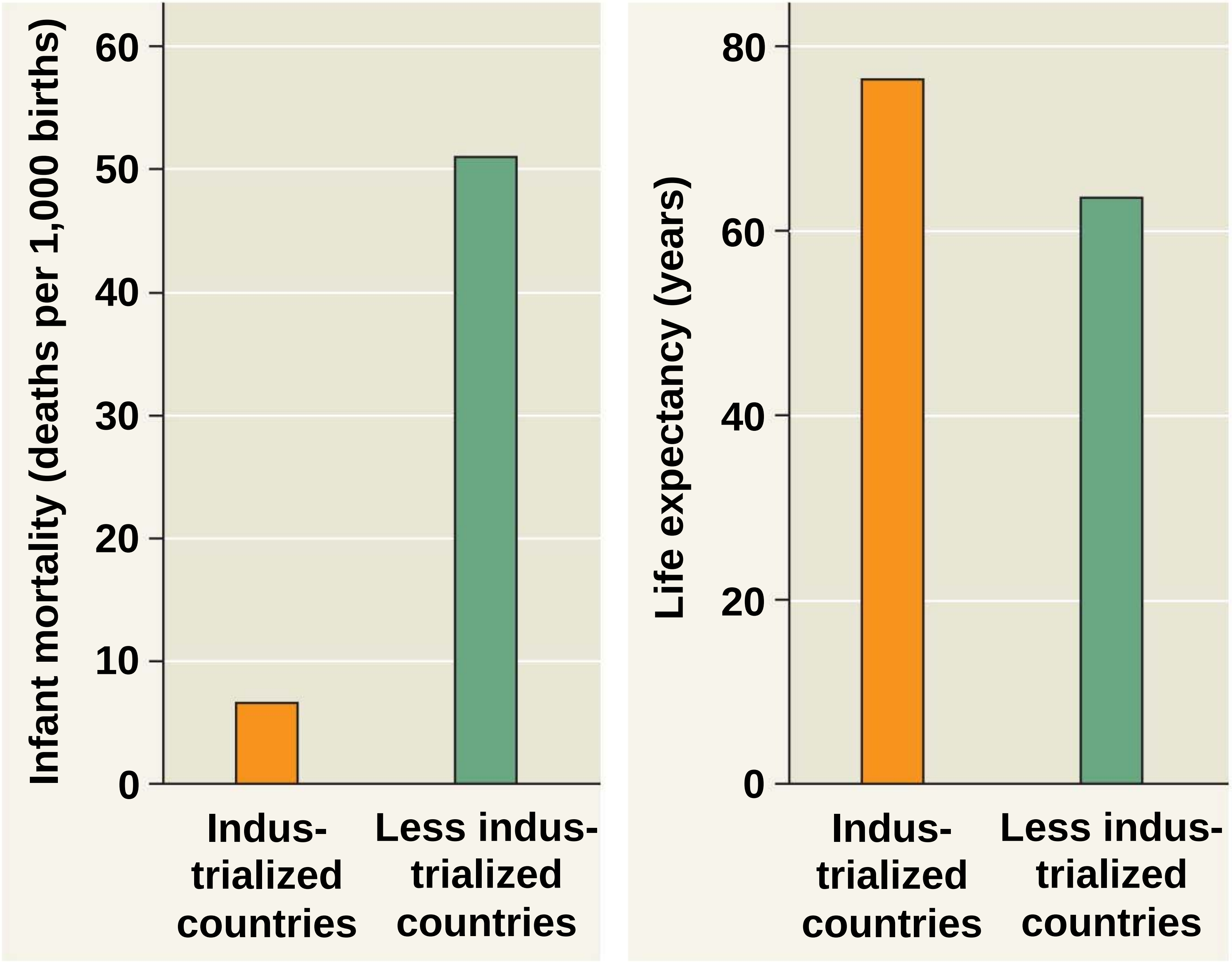
Rapid growth
Afghanistan
Male
Female
Age
Slow growth
United States
Male
Female
Age
No growth
Italy
Male
Female
85+
80–84
75–79
70–74
65–69
60–64
55–59
50–54
45–49
40–44
35–39
30–34
25–29
20–24
15–19
10–14
5–9
0–4
10 8 6 4 2 0 2 4 6 8 10
8 6 4 2 0 2 4 6 8
8 6 4 2 0 2 4 6 8
Percent of population
Percent of population
Percent of population

- 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

Fig. 53-26


Infant mortality (deaths per 1,000 births)
60
50
40
30
20
10
0
Indus-trialized countries
Less indus-trialized countries
Life expectancy (years)
80
60
40
20
0
Indus-trialized countries
Less indus-trialized countries

Global Carrying Capacity

- How many humans can the biosphere support?

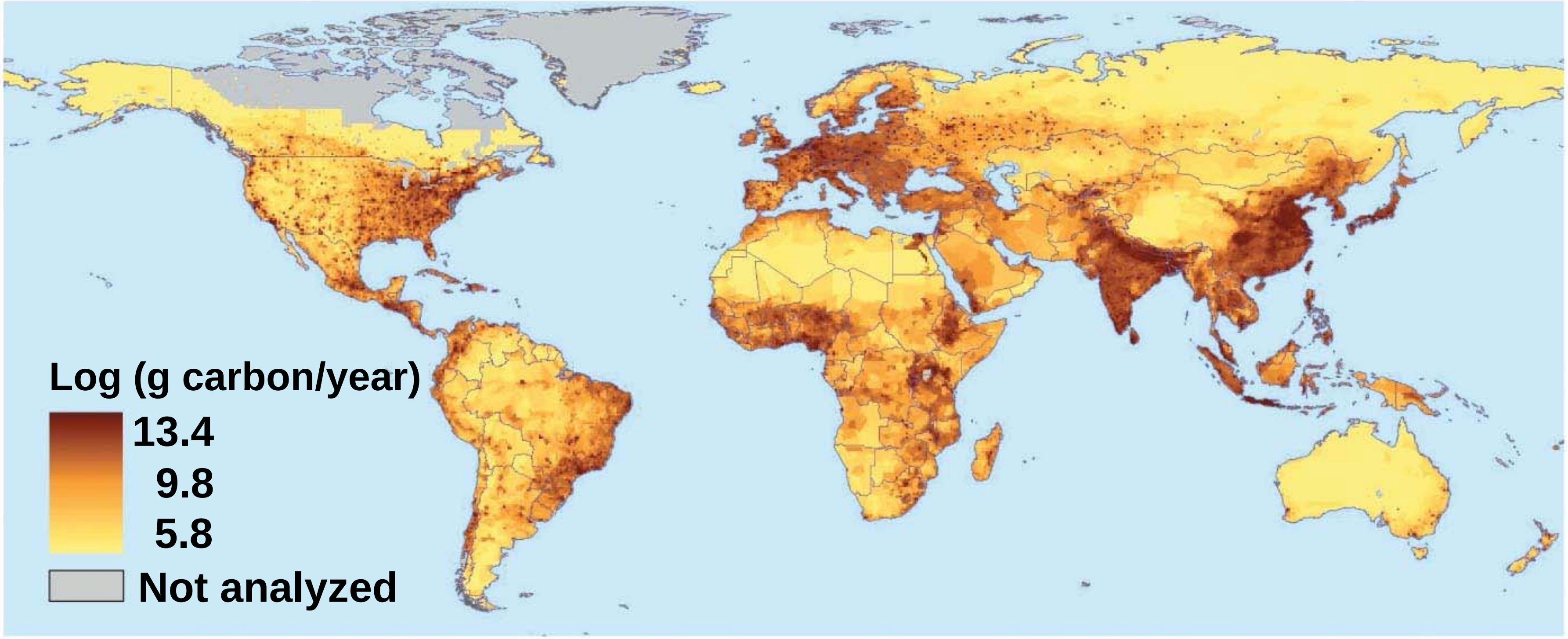
Estimates of Carrying Capacity

- 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

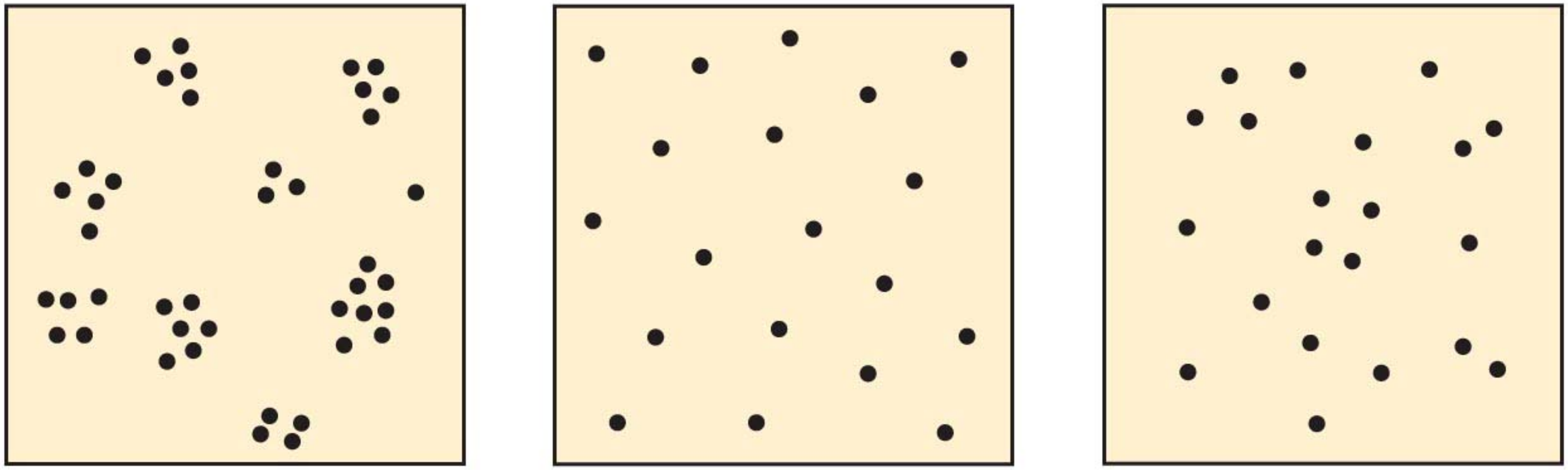
Fig. 53-27



- Our carrying capacity could potentially be limited by food, space, nonrenewable resources, or buildup of wastes

Fig. 53-UN1

Patterns of dispersion

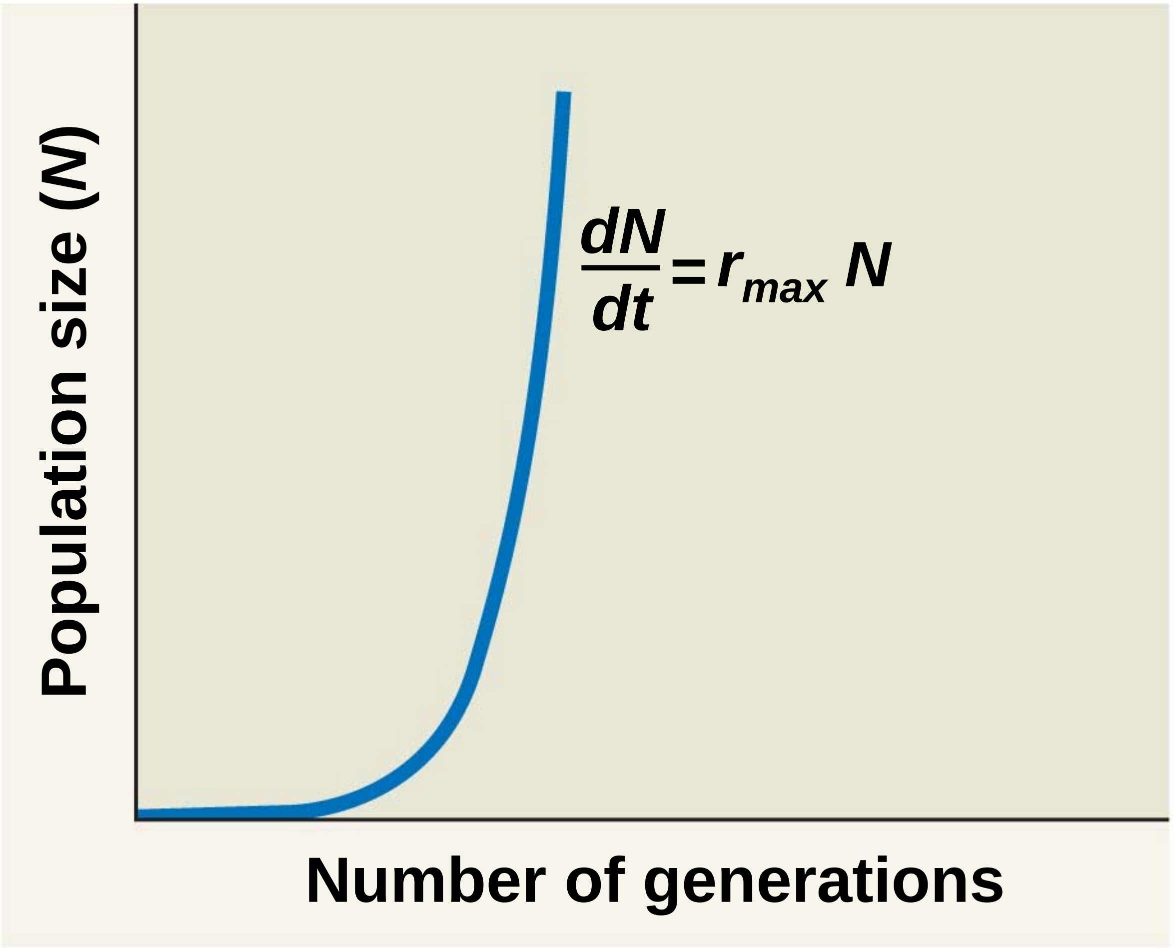


Clumped

Uniform

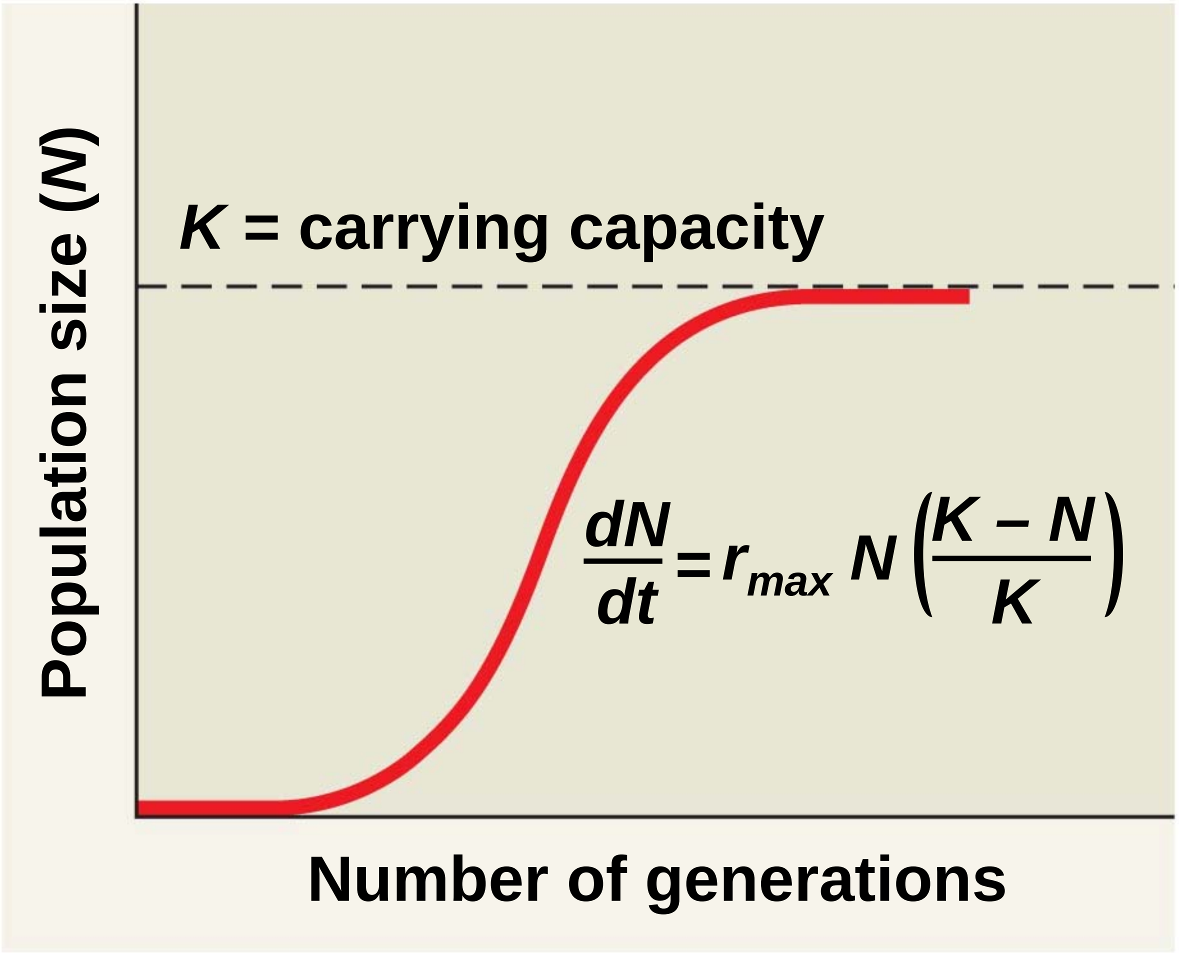
Random

Fig. 53-UN2



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

Fig. 53-UN3



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

Fig. 53-UN4

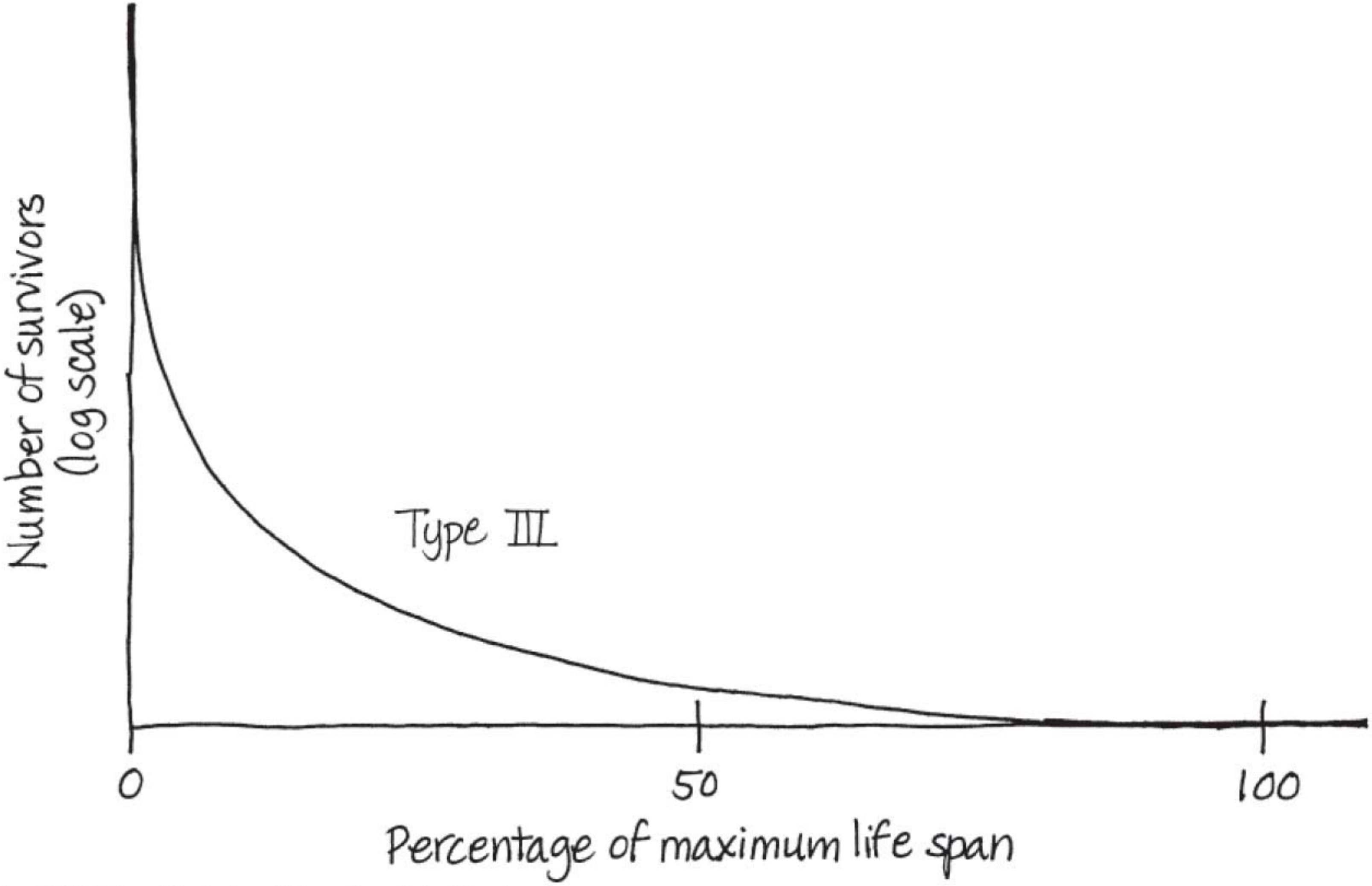
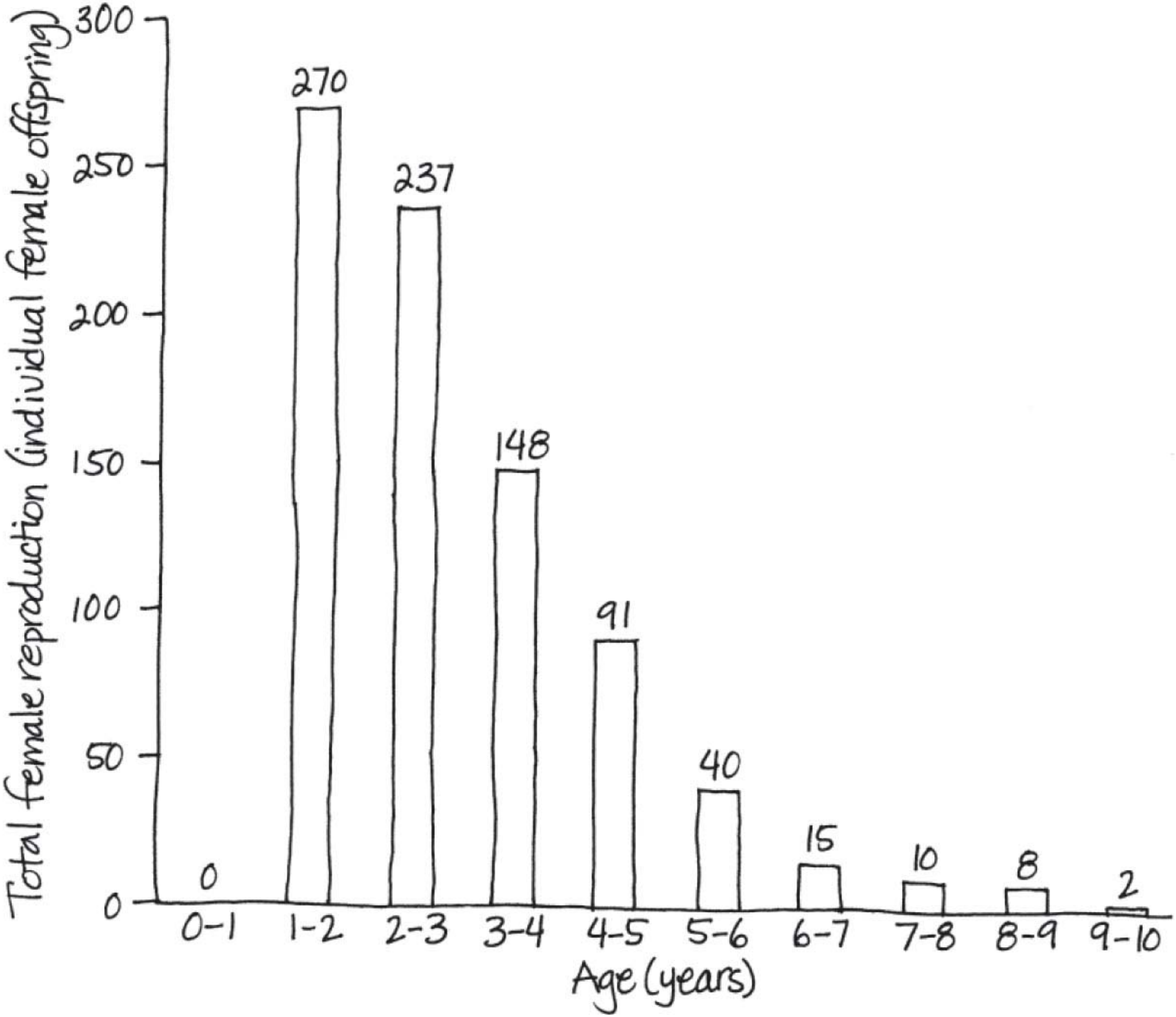

Number of survivors (log scale)
Type III
0
50
100
Percentage of maximum life span

Fig. 53-UN5


Total female reproduction (individual female offspring)
300
250
200
150
100
50
0
0
270
237
148
91
40
15
10
8
2
0–1
1–2
2–3
3–4
4–5
5–6
6–7
7–8
8–9
9–10
Age (years)

You should now be able to:

1. Define and distinguish between the following sets of terms: density and dispersion; clumped dispersion, uniform dispersion, and random dispersion; life table and reproductive table; Type I, Type II, and Type III survivorship curves; semelparity and iteroparity; *r*-selected populations and *K*-selected populations
2. Explain how ecologists may estimate the density of a species

3. Explain how limited resources and trade-offs may affect life histories
4. Compare the exponential and logistic models of population growth
5. Explain how density-dependent and density-independent factors may affect population growth
6. Explain how biotic and abiotic factors may work together to control a population's growth

7. Describe the problems associated with estimating Earth’s carrying capacity for the human species
8. Define the demographic transition