Chapter 53

Population Ecology

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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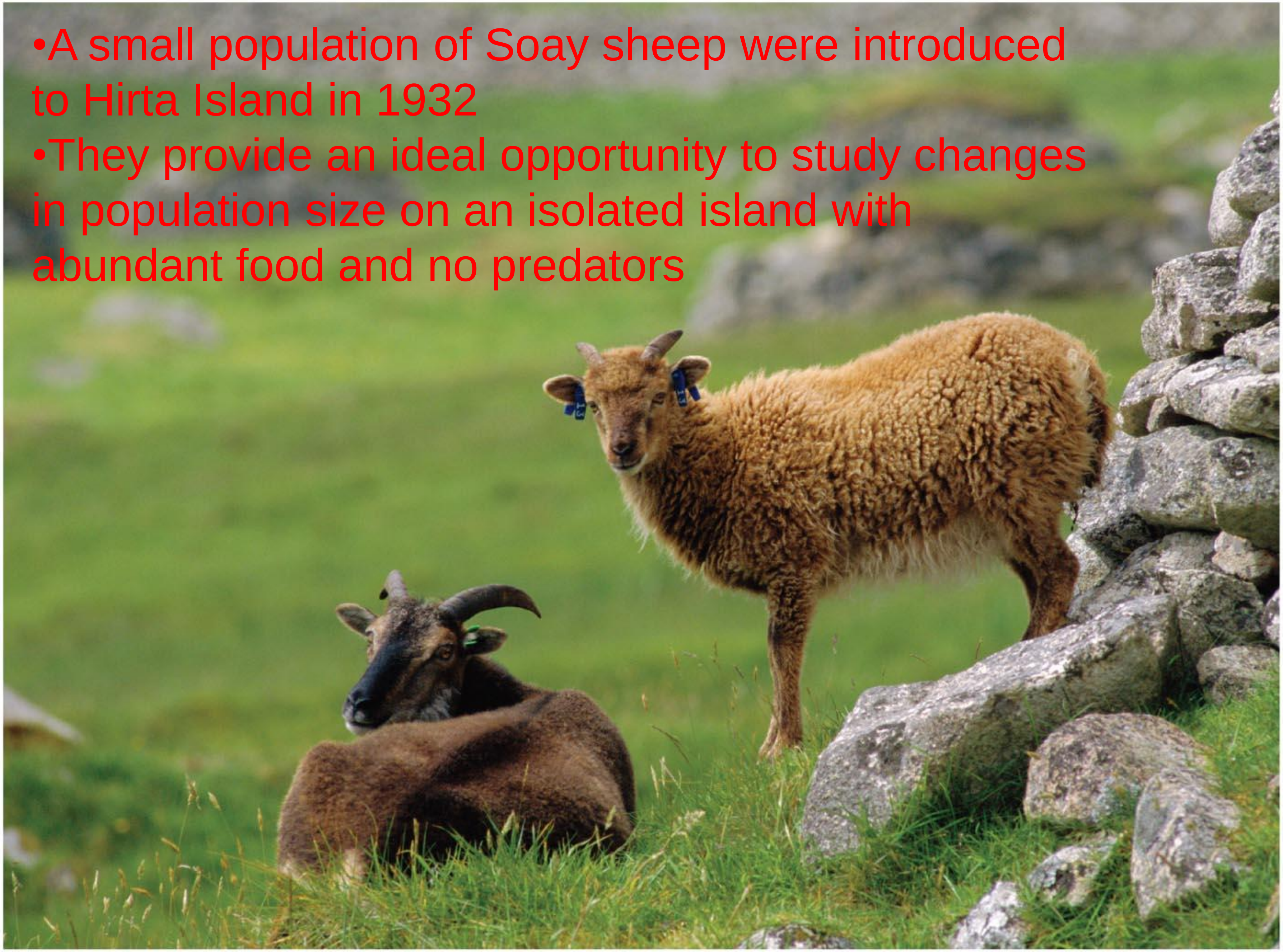
Key concepts

1. Population ecology concerns factors that affect the increase and decrease of a species in a habitat.
2. Human population is a unique challenge for population ecologists.

Fig. 53-1

- 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



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

- Population size can be estimated by either extrapolation from small samples, an index of population size, or the **mark-recapture method**

Hector's dolphins

Fig. 53-3

Population dynamics

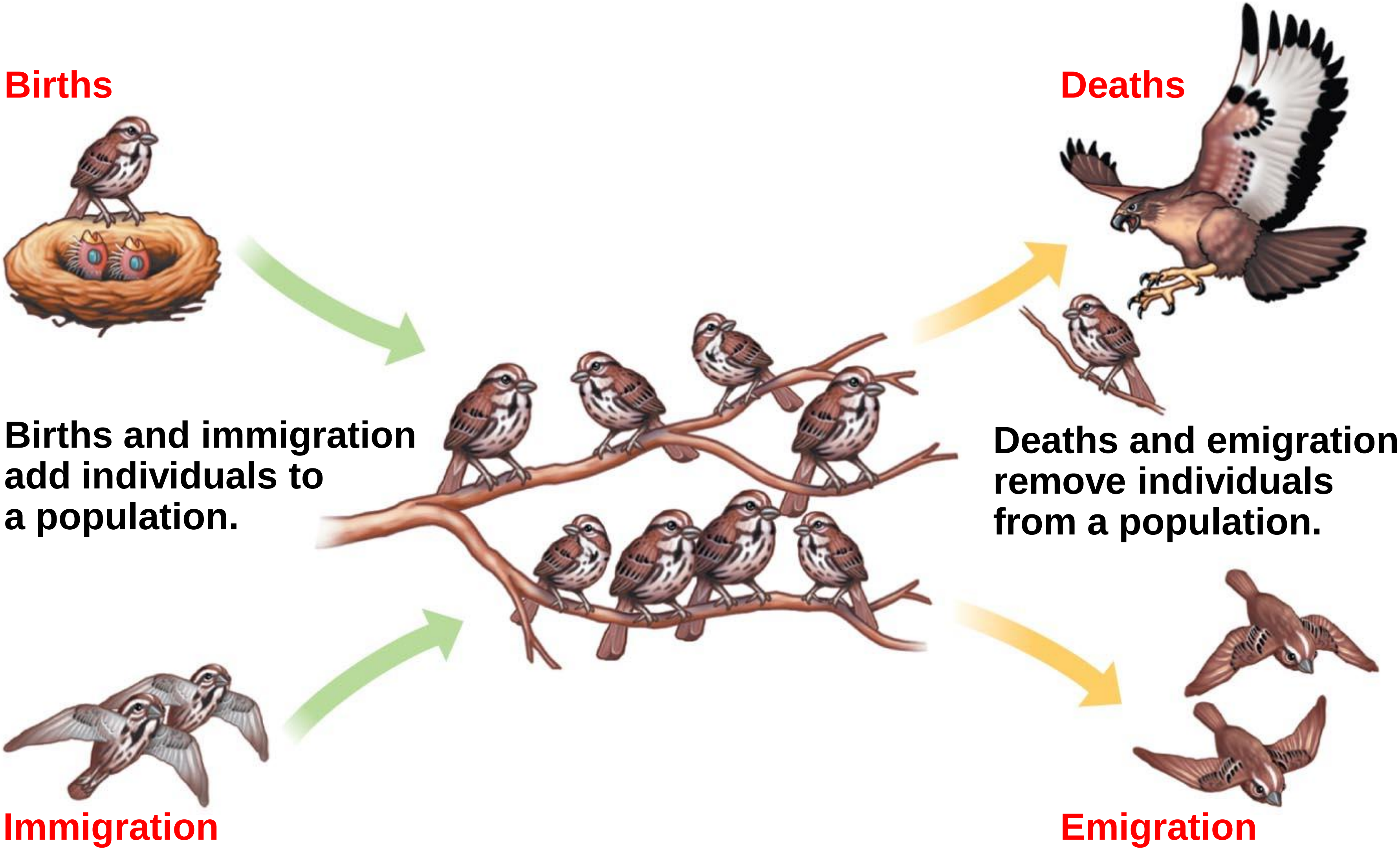
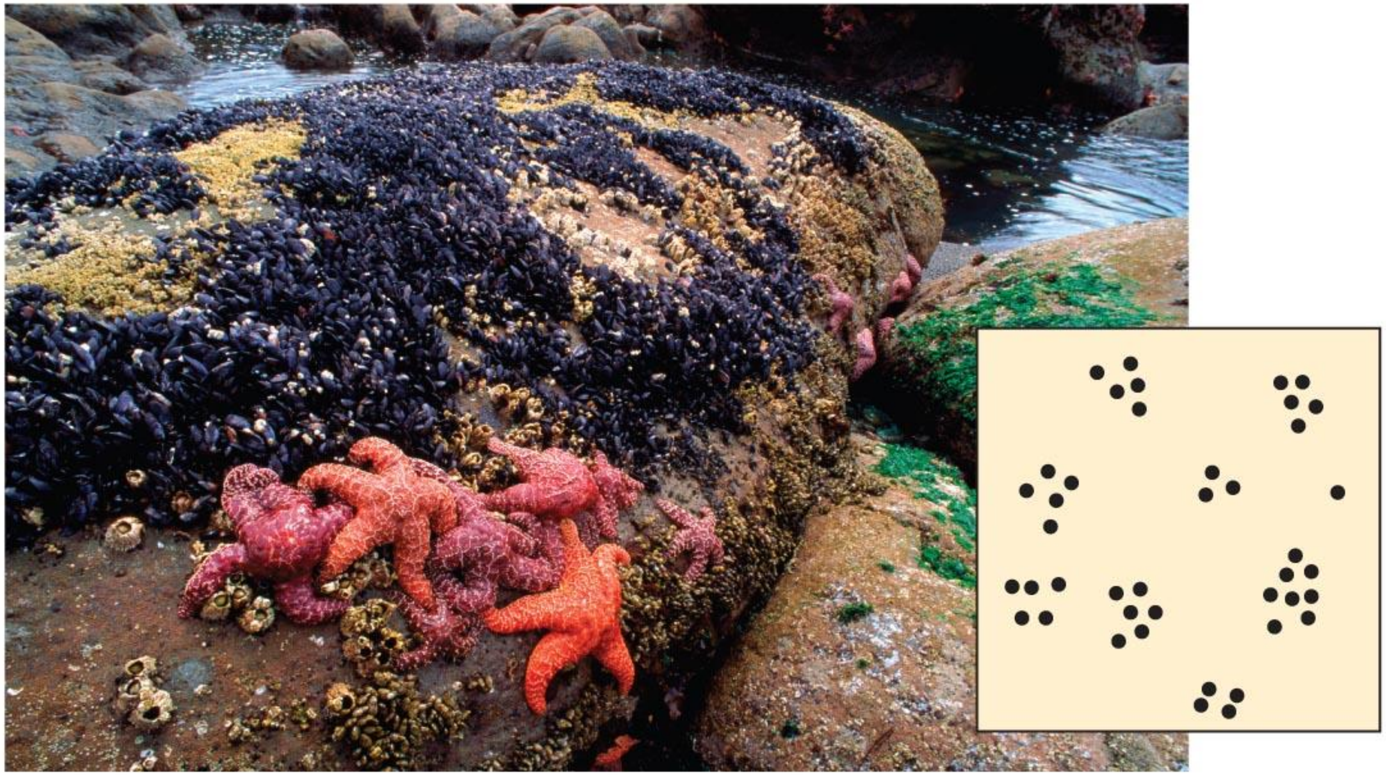


Fig. 53-4a

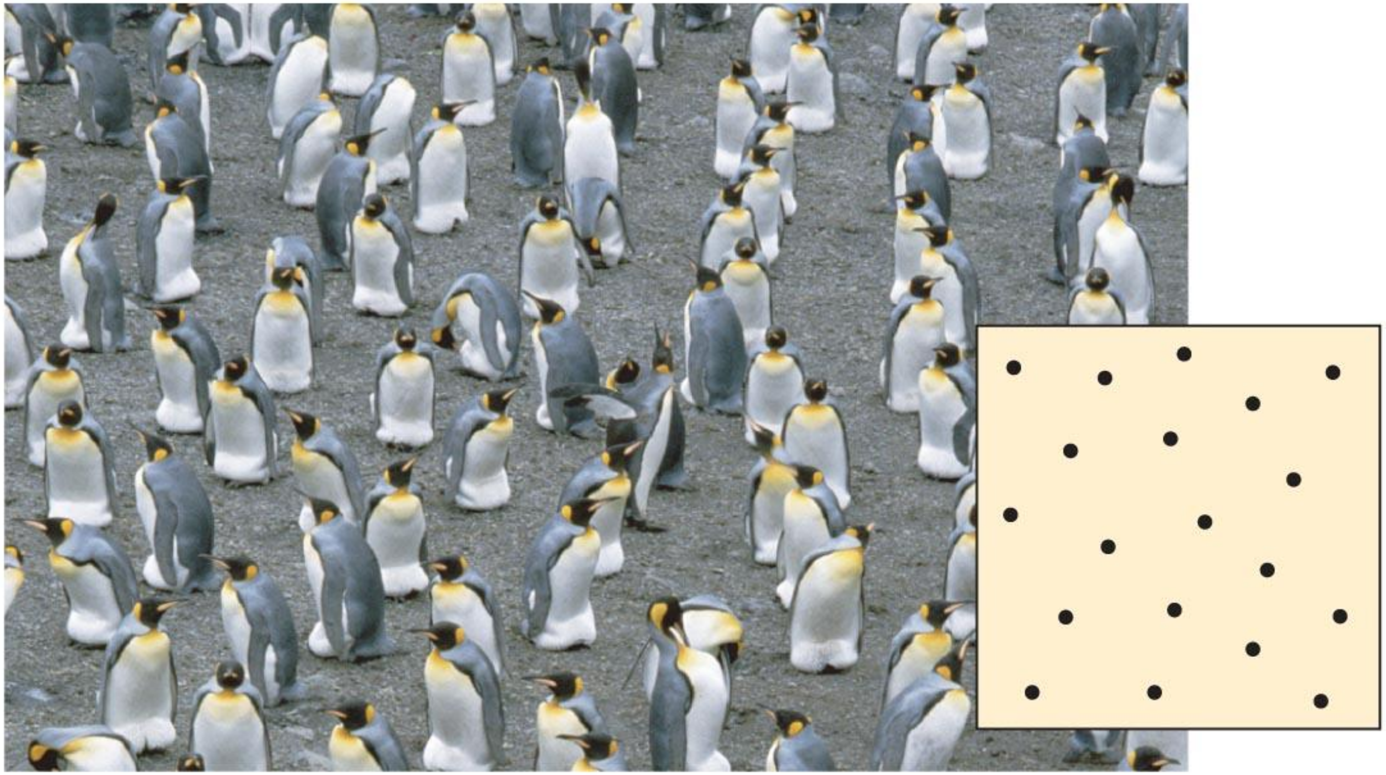
A clumped dispersion may be influenced by resource availability and behavior



(a) Clumped

Fig. 53-4b

It may be influenced by social interactions such as **territoriality**



(b) Uniform

Fig. 53-4c

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

Table 53-1

A **life table** is an age-specific summary of the survival pattern of a population

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

	FEMALES					MALES				
Age (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)	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).

Fig. 53-5

Survivorship curves for male and female Belding's ground squirrels

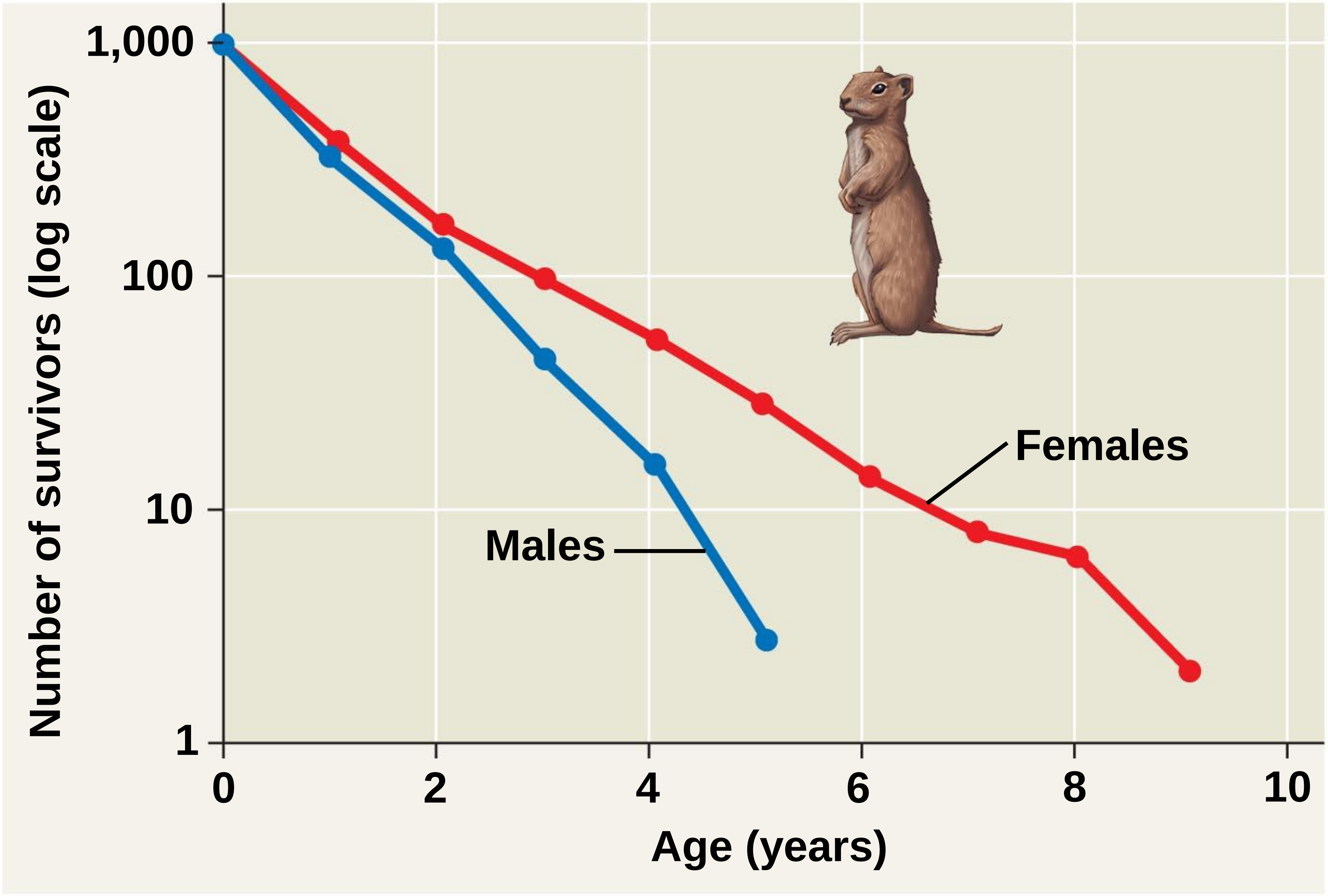
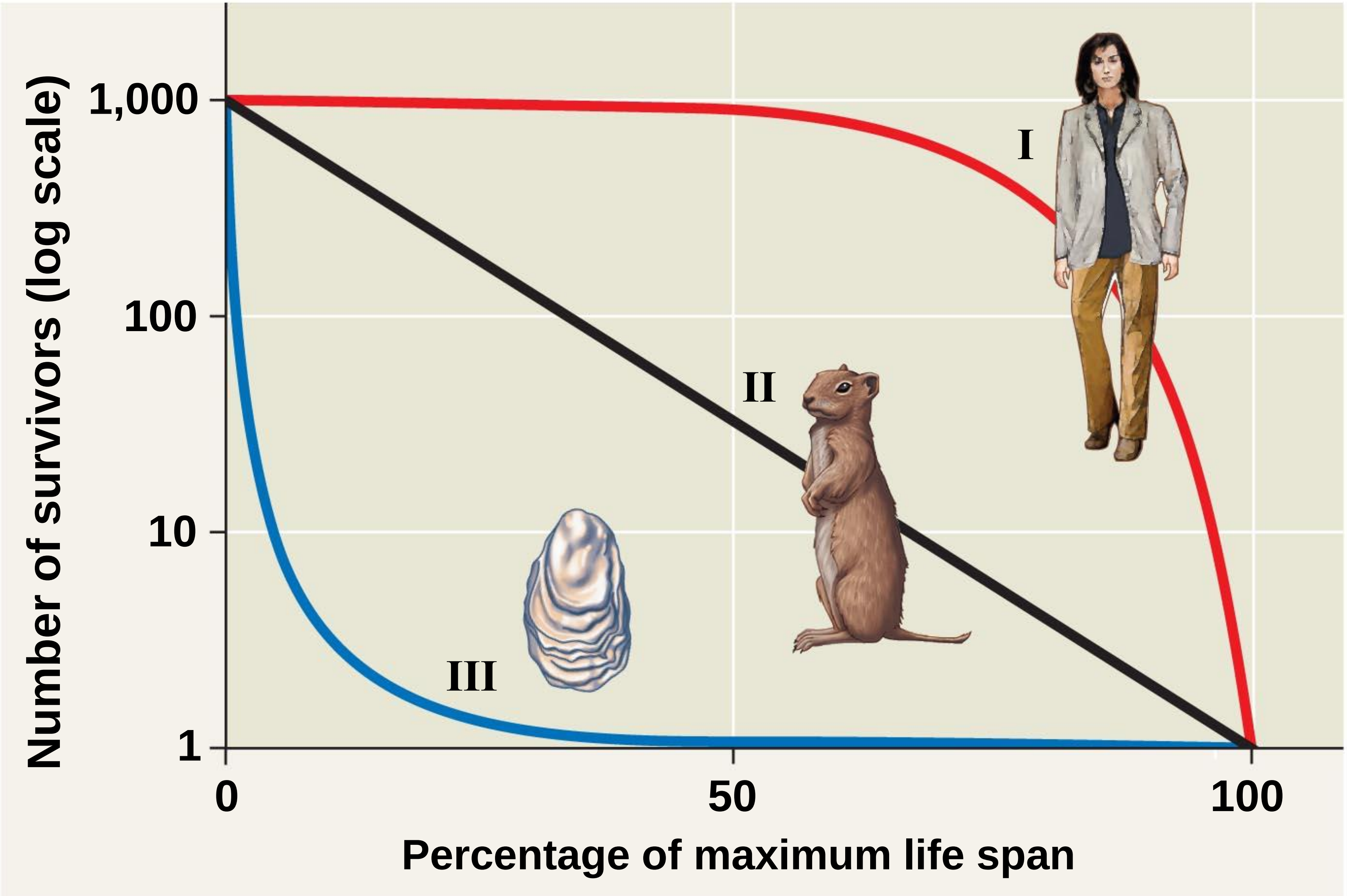


Fig. 53-6

Idealized survivorship curves: Types I, II, and 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

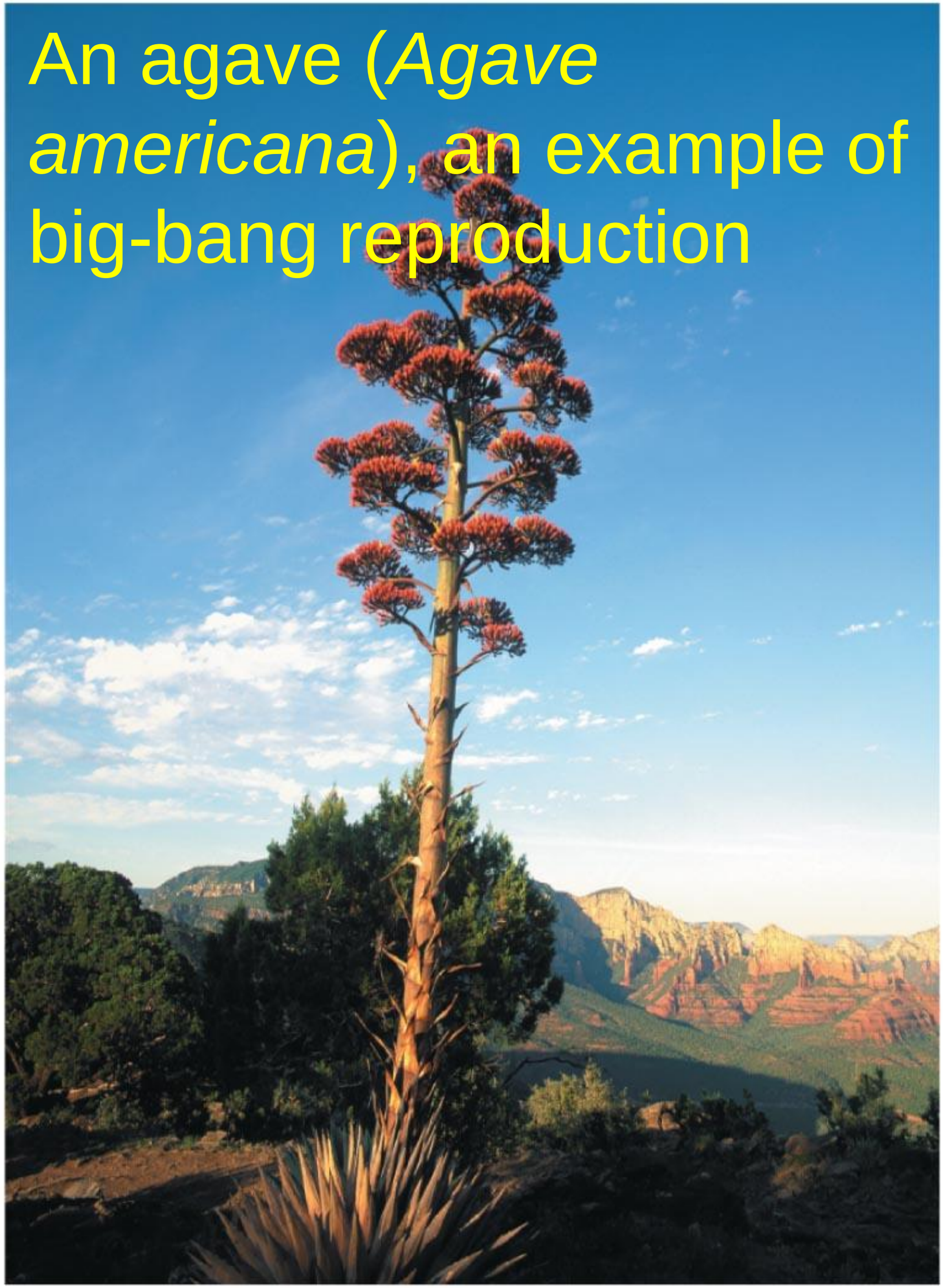
*The average number of female offspring is the proportion weaning a litter multiplied by the mean number of females in a litter.

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

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


An agave (*Agave americana*), an example of big-bang reproduction

"Trade-offs" and Life Histories

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

Fig. 53-8

RESULTS

How does caring for offspring affect parental survival in kestrels?

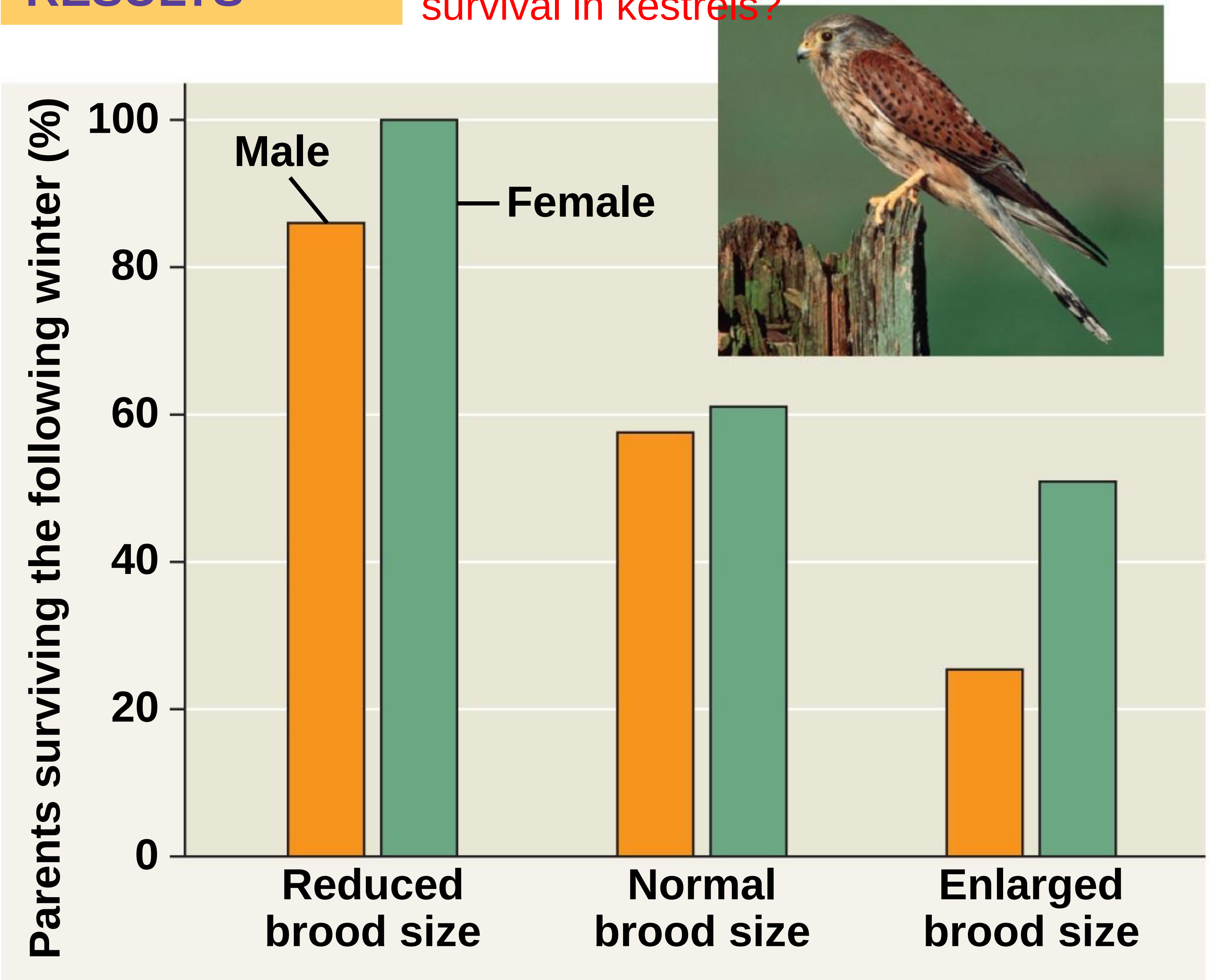


Fig. 53-9

Variation in the size of seed crops in plants

(a) Dandelion

(b) Coconut palm

- **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:

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

Fig. 53-10

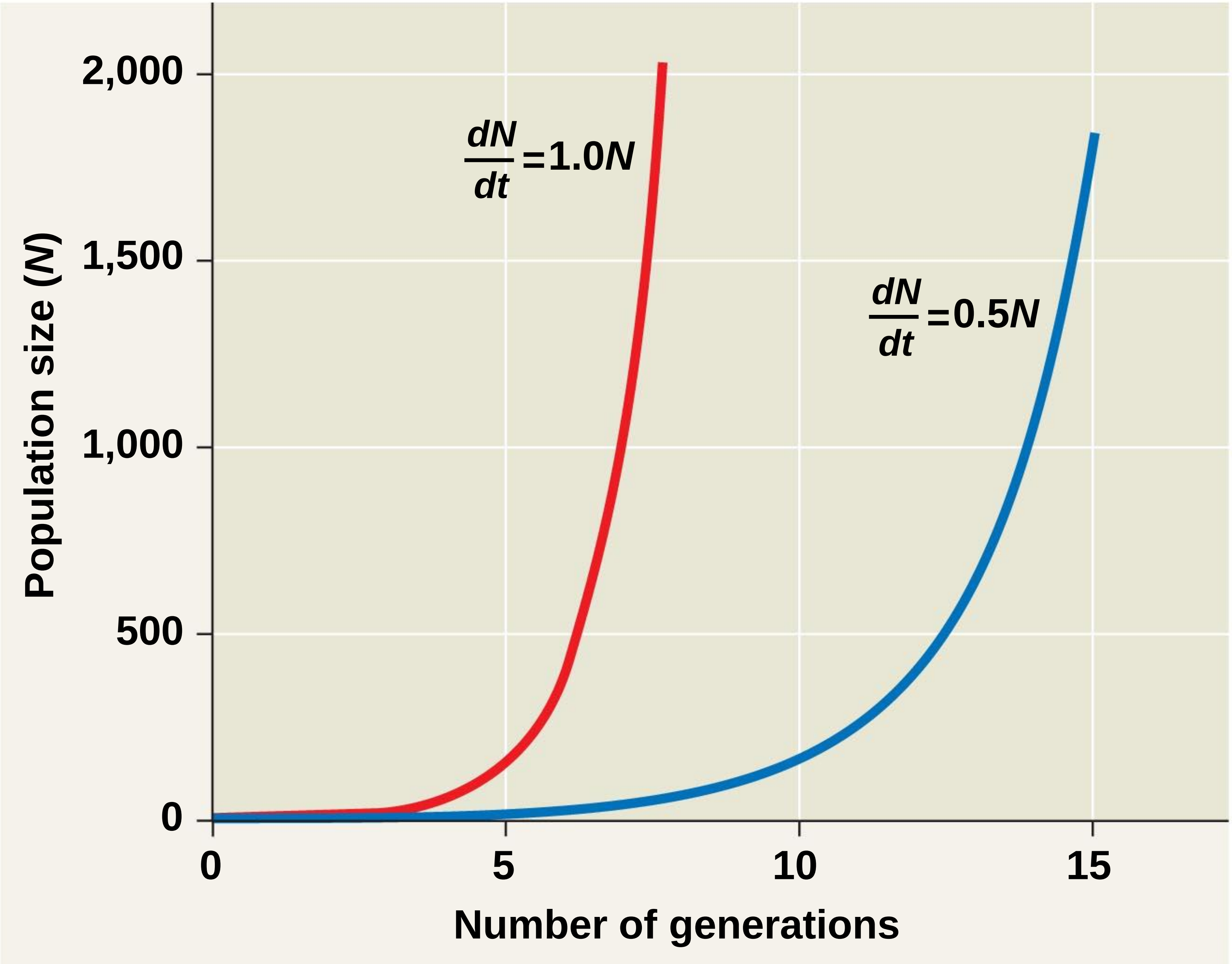
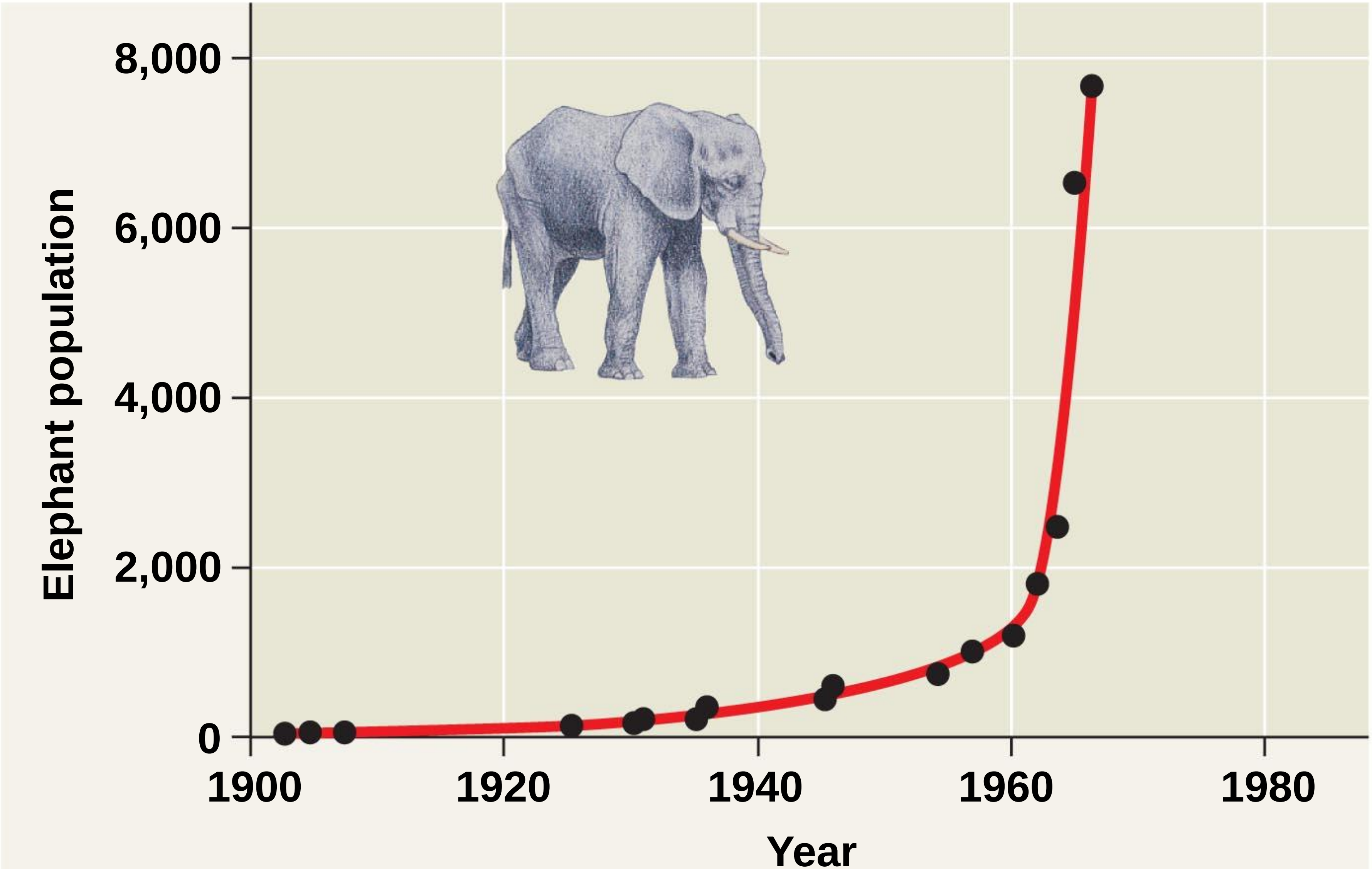

2,000
1,500
1,000
500
0
Population size (N)
dN/dt = 1.0N
dN/dt = 0.5N
0
5
10
15
Number of generations

Fig. 53-11

Exponential growth in the African elephant population of Kruger National Park, South Africa



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*

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

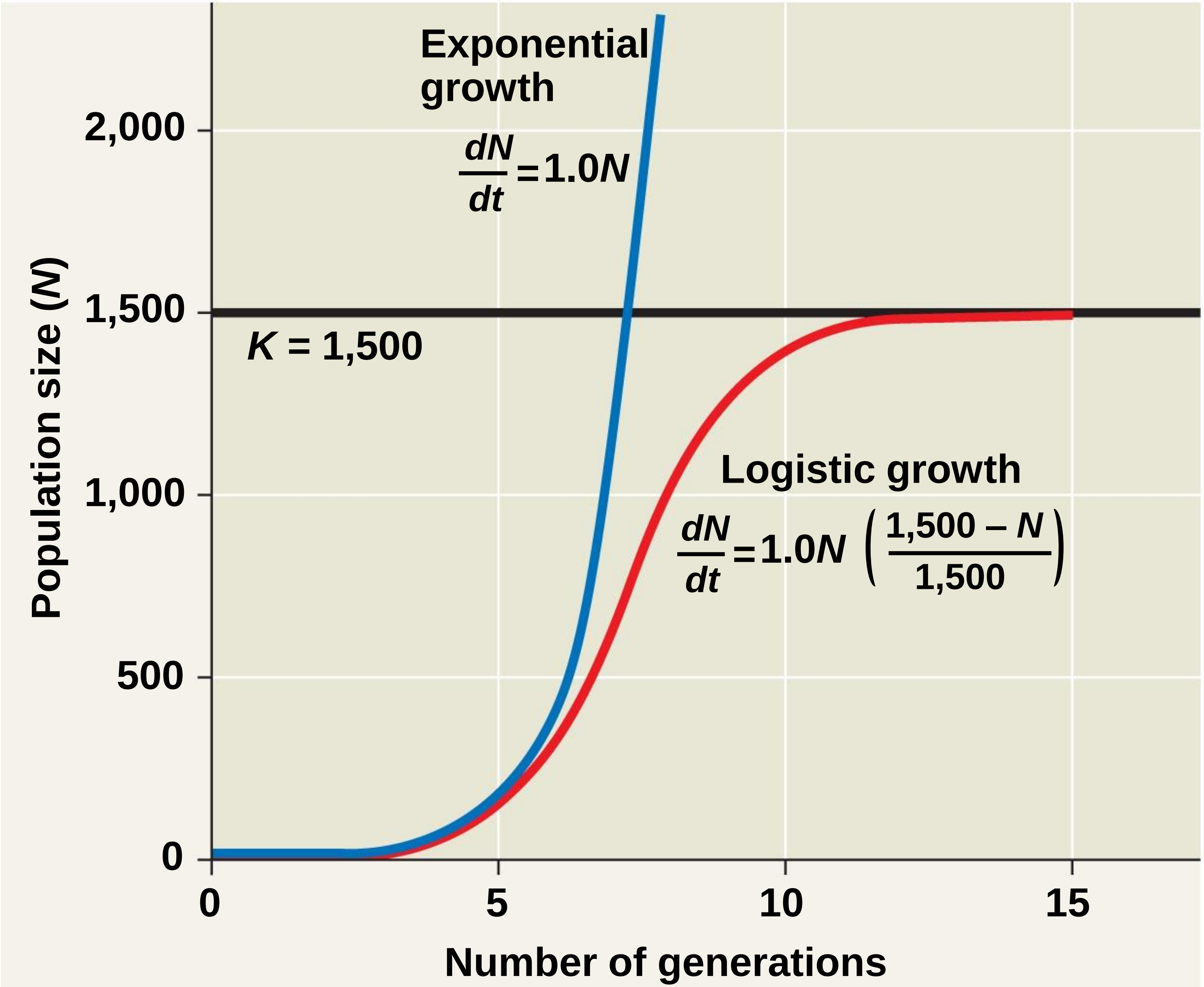
Table 53-3

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.

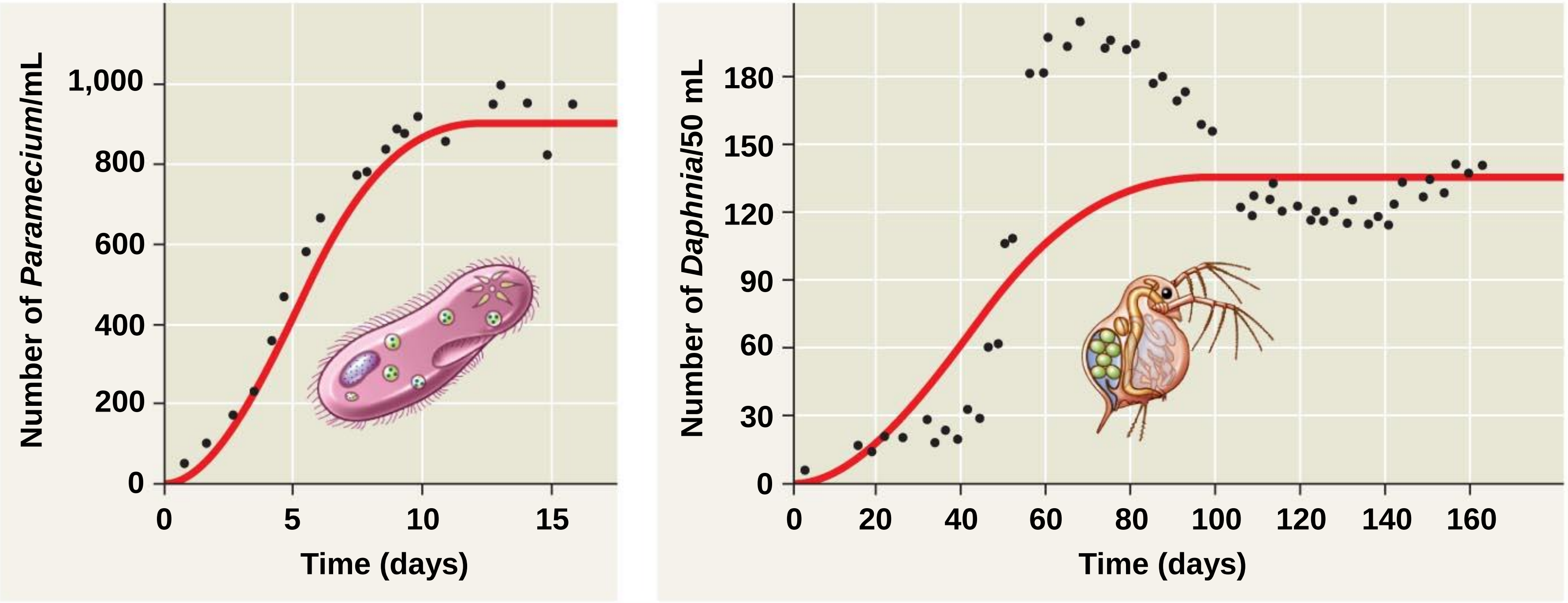
Fig. 53-12



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

Fig. 53-13

How well do these populations fit the logistic growth model?



(a) A *Paramecium* population in the lab

(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

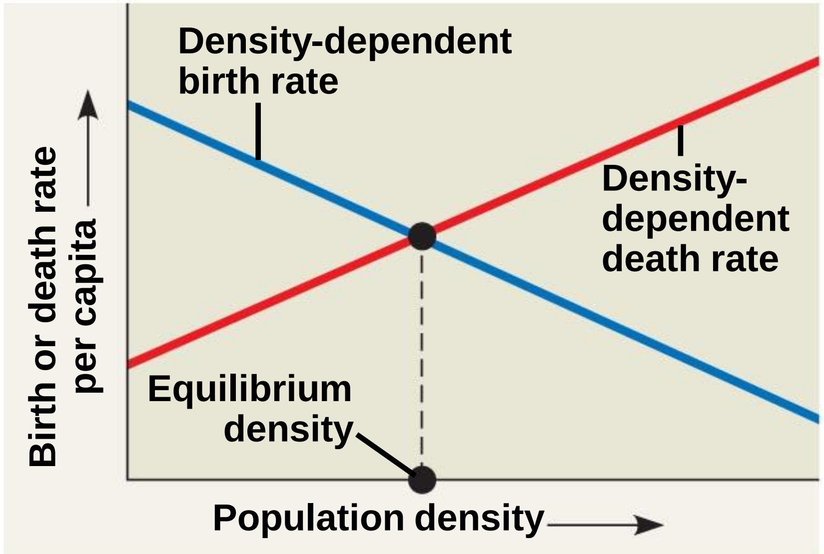
The Logistic Model and Life Histories

- 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

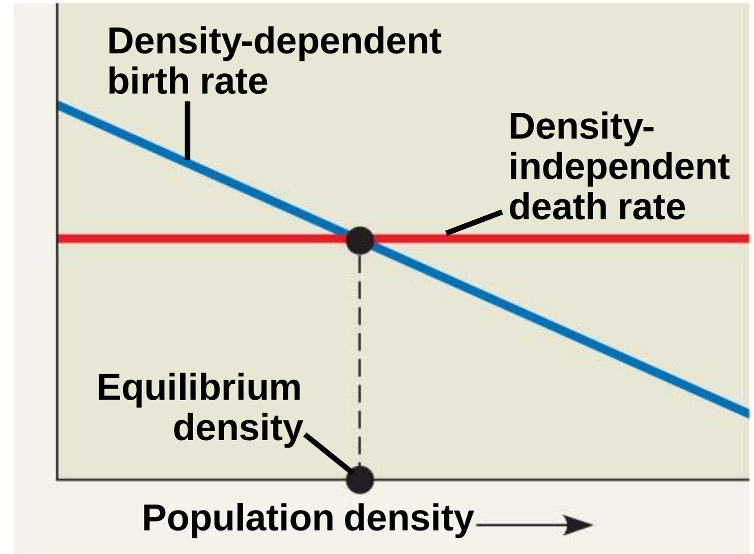
Concept 53.5: Many factors that regulate population growth are density dependent

- 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?

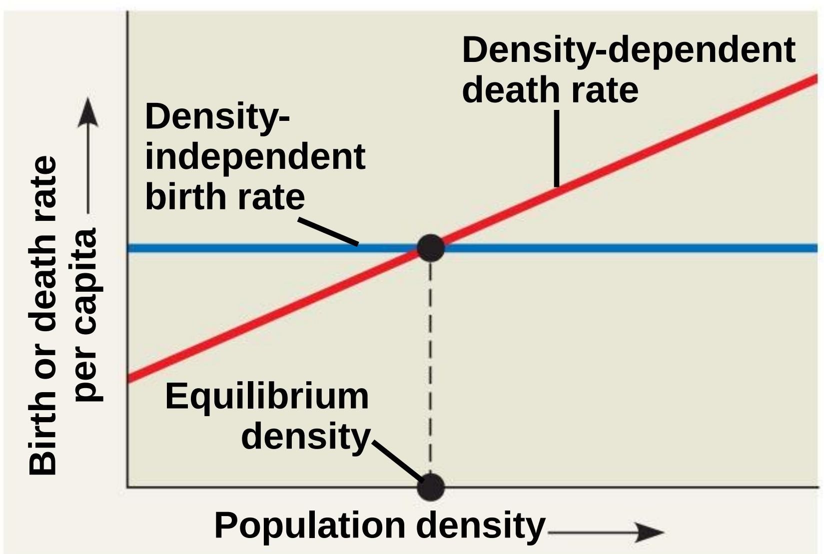
Fig. 53-15



(a) Both birth rate and death rate vary.



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



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

Fig. 53-16

Decreased reproduction at high population densities

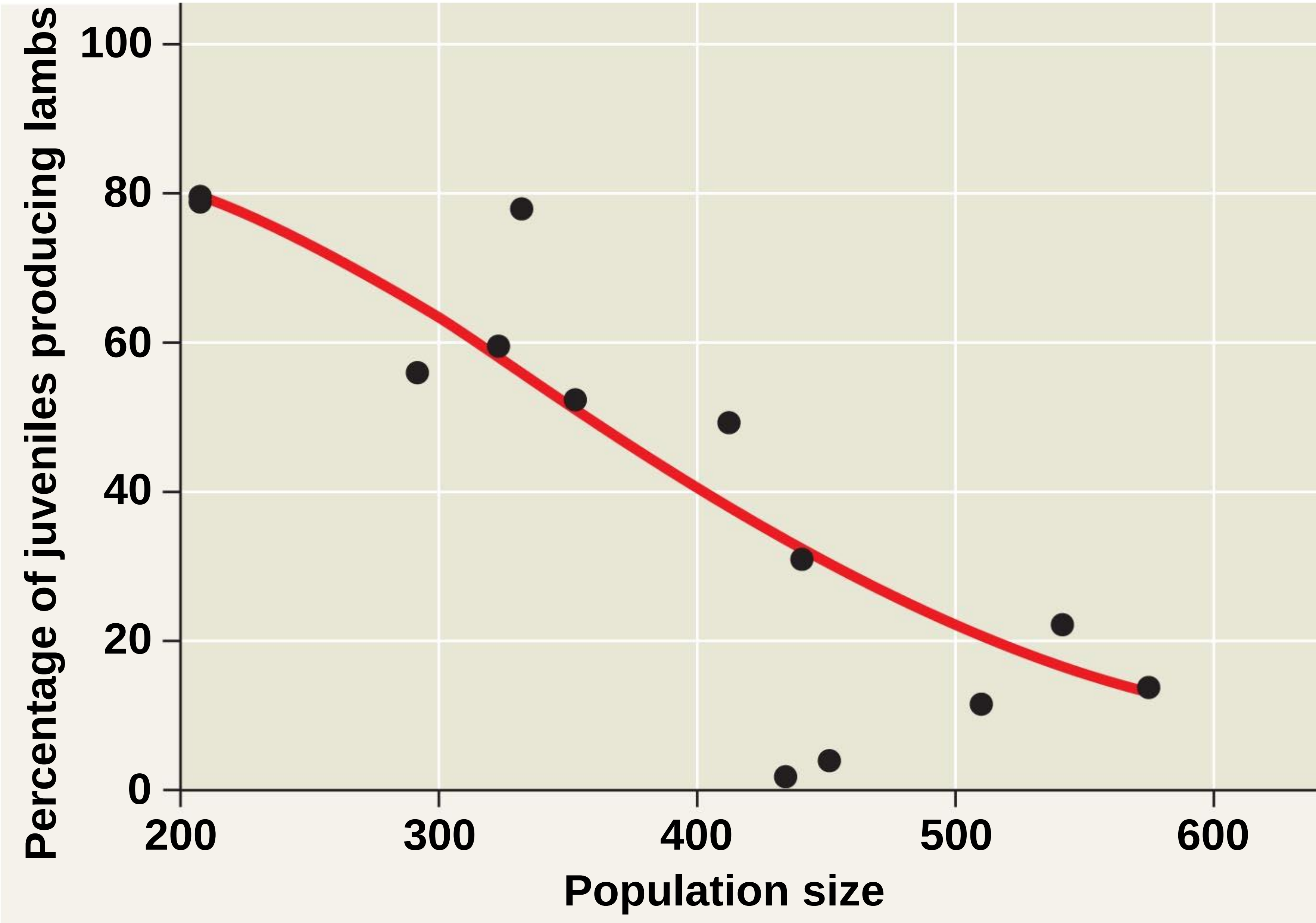


Fig. 53-17

(a) Cheetah marking its territory

(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

Fig. 53-18

Variation in size of the Soay sheep population on Hirta Island, 1955–2002

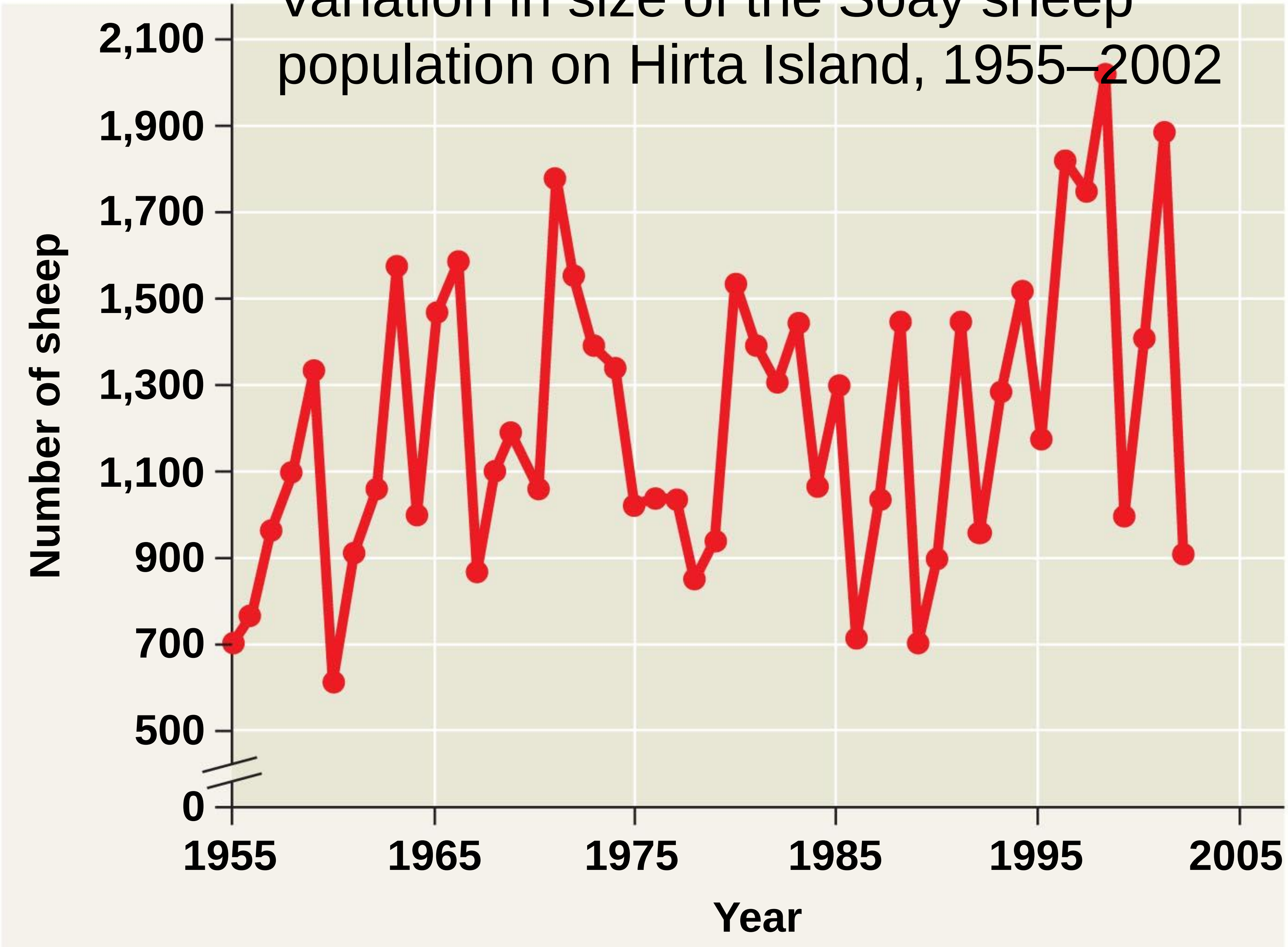


Fig. 53-19

Fluctuations in moose and wolf populations on Isle Royale, 1959–2006

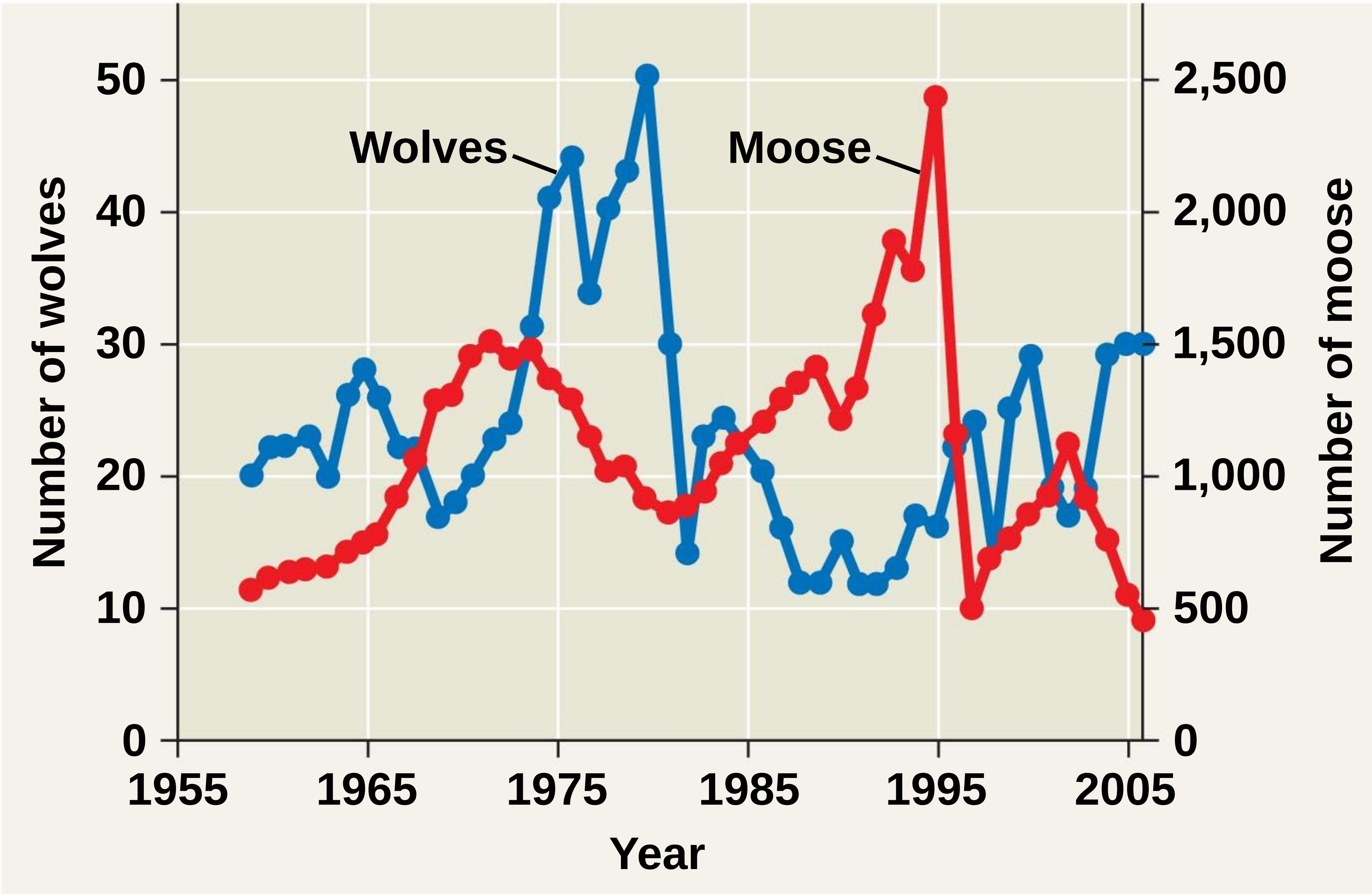
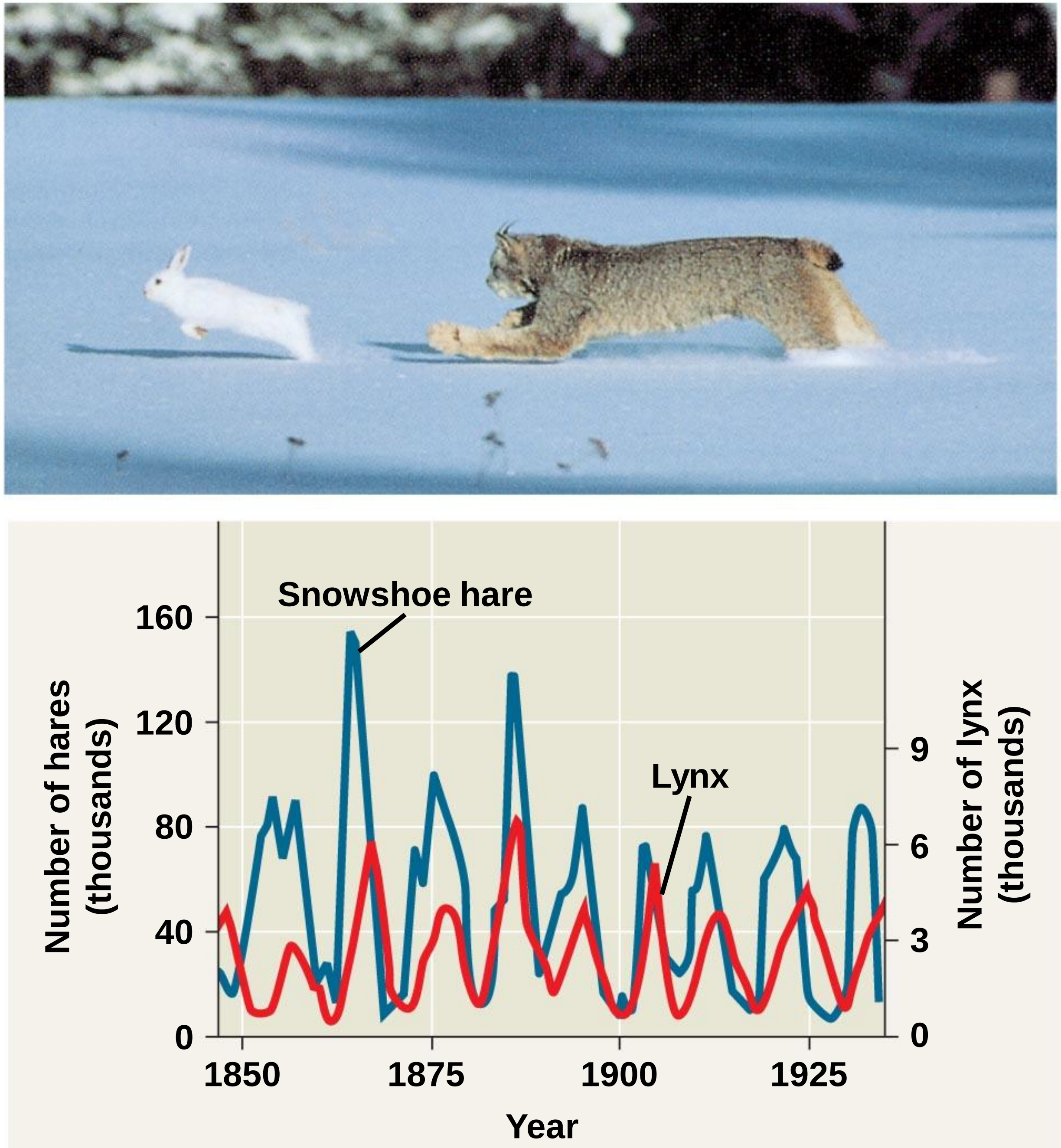


Fig. 53-20



Snowshoe hare
Lynx
160
120
80
40
0
Number of hares (thousands)
9
6
3
0
Number of lynx (thousands)
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

ECOLOGY

Mothers stress kids out

Ecology doi:10.1890/09-1108 (2010)

Snowshoe hares in the Canadian territory of Yukon undergo a 10-year cycle of population growth and collapse, closely followed by a similar trend in predator numbers. However, there is a perplexingly slow rebound in the number of hares (*Lepus americanus*, pictured below with predator) after the decline has ended, even when predators have all but disappeared and food is abundant.

Michael Sheriff at the University of British Columbia in Vancouver, Canada, and his colleagues show that high levels of predation result in a sharp increase in levels of maternal stress hormones. These levels remain high in the offspring of these stressed animals and persist into adulthood, depressing reproduction. This suggests that the inheritance of stress levels results in a slow recovery of a population of wild mammals, supporting laboratory studies.

Fig. 53-21

Metapopulations are groups of populations linked by immigration and emigration

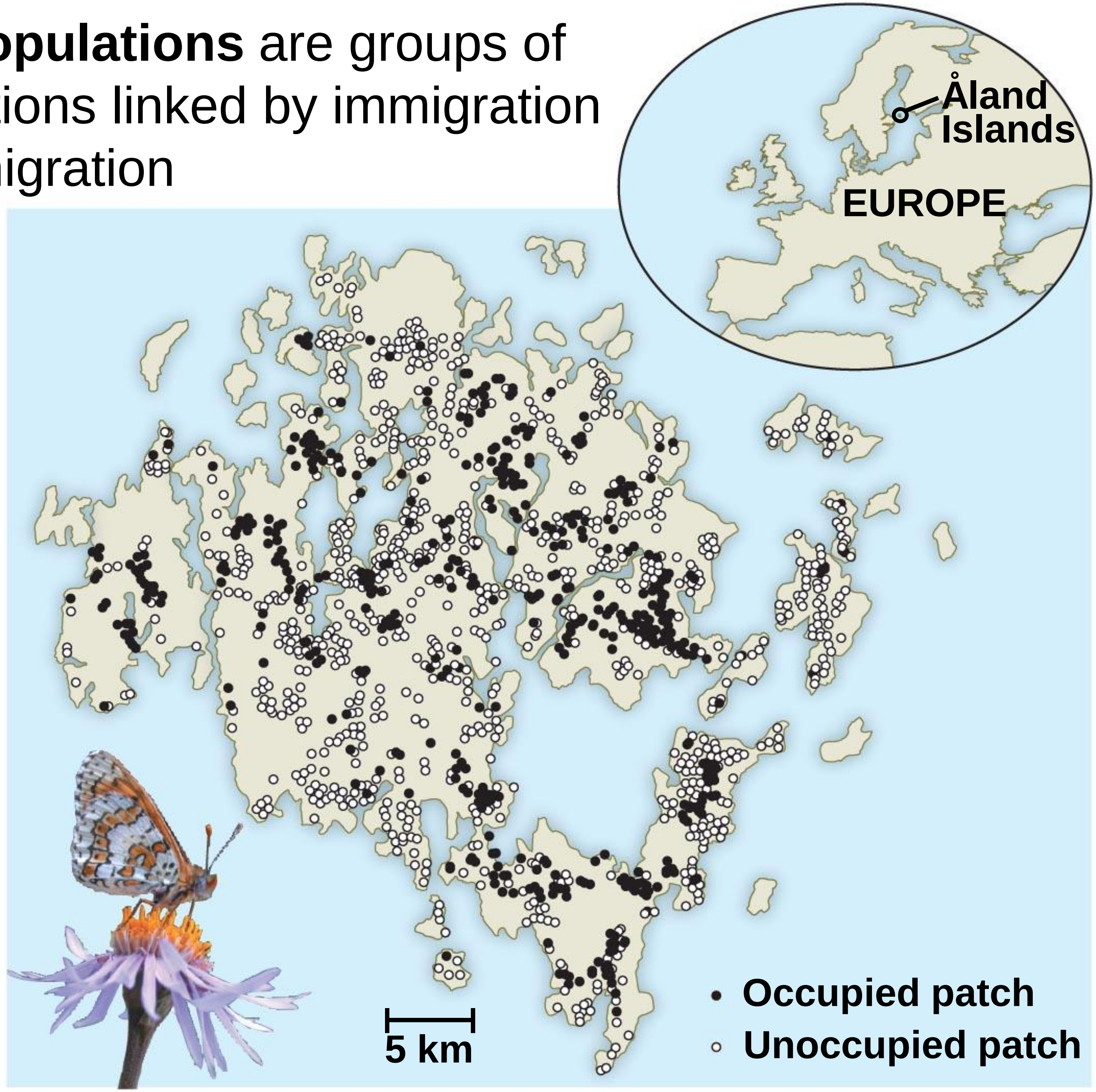


Fig. 53-22

Human population growth (data as of 2006)

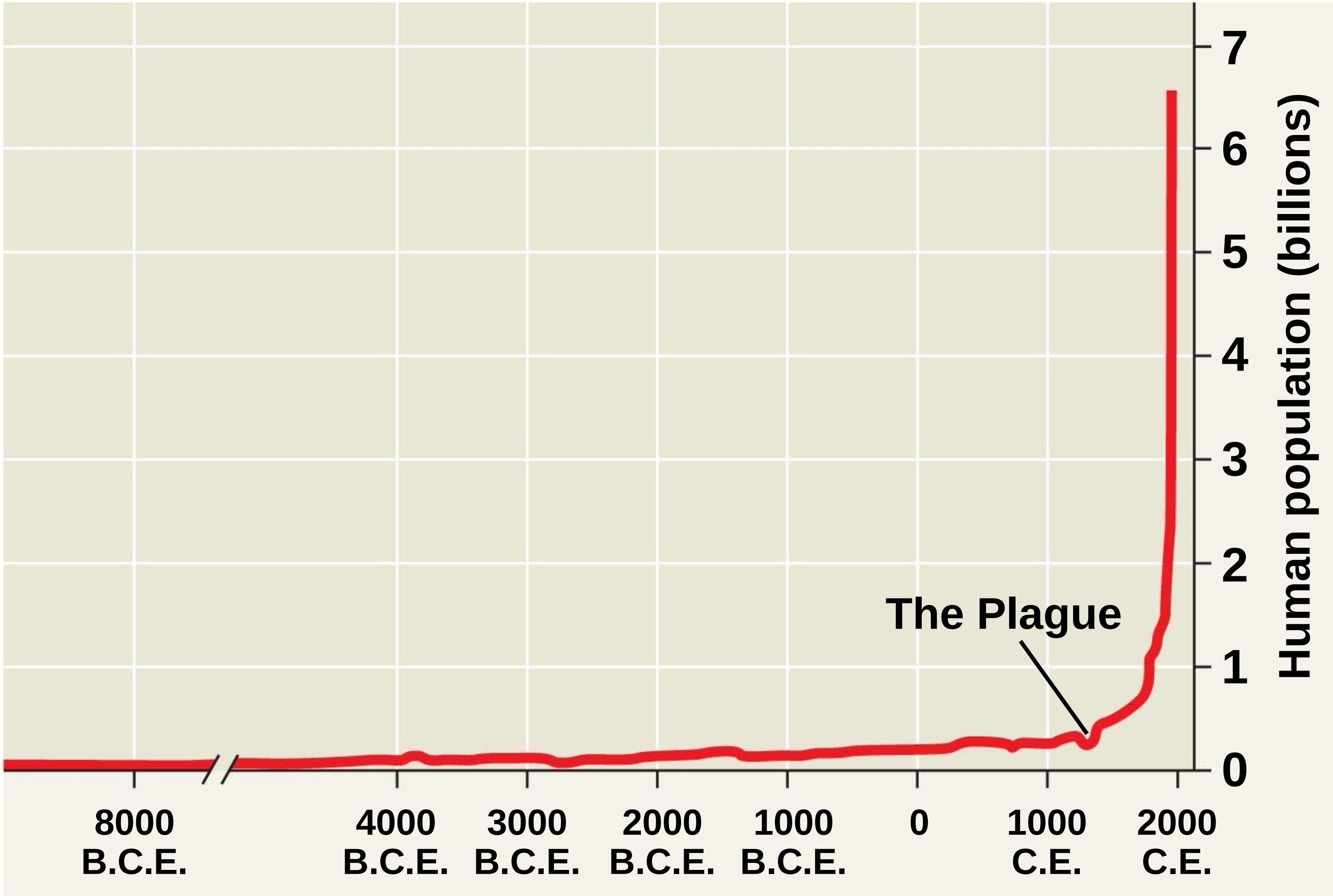
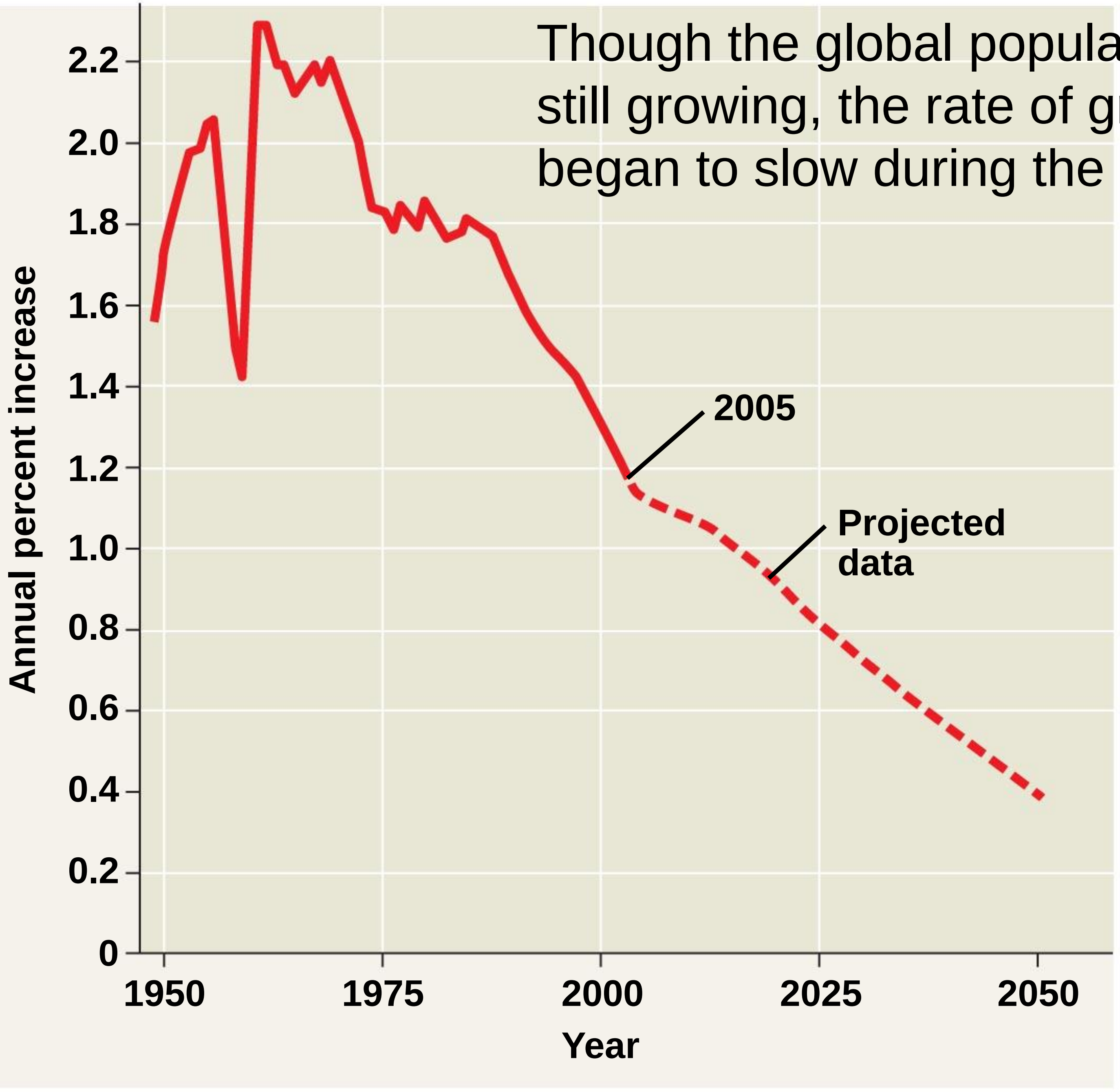


Fig. 53-23



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

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

Demographic transition in Sweden and Mexico

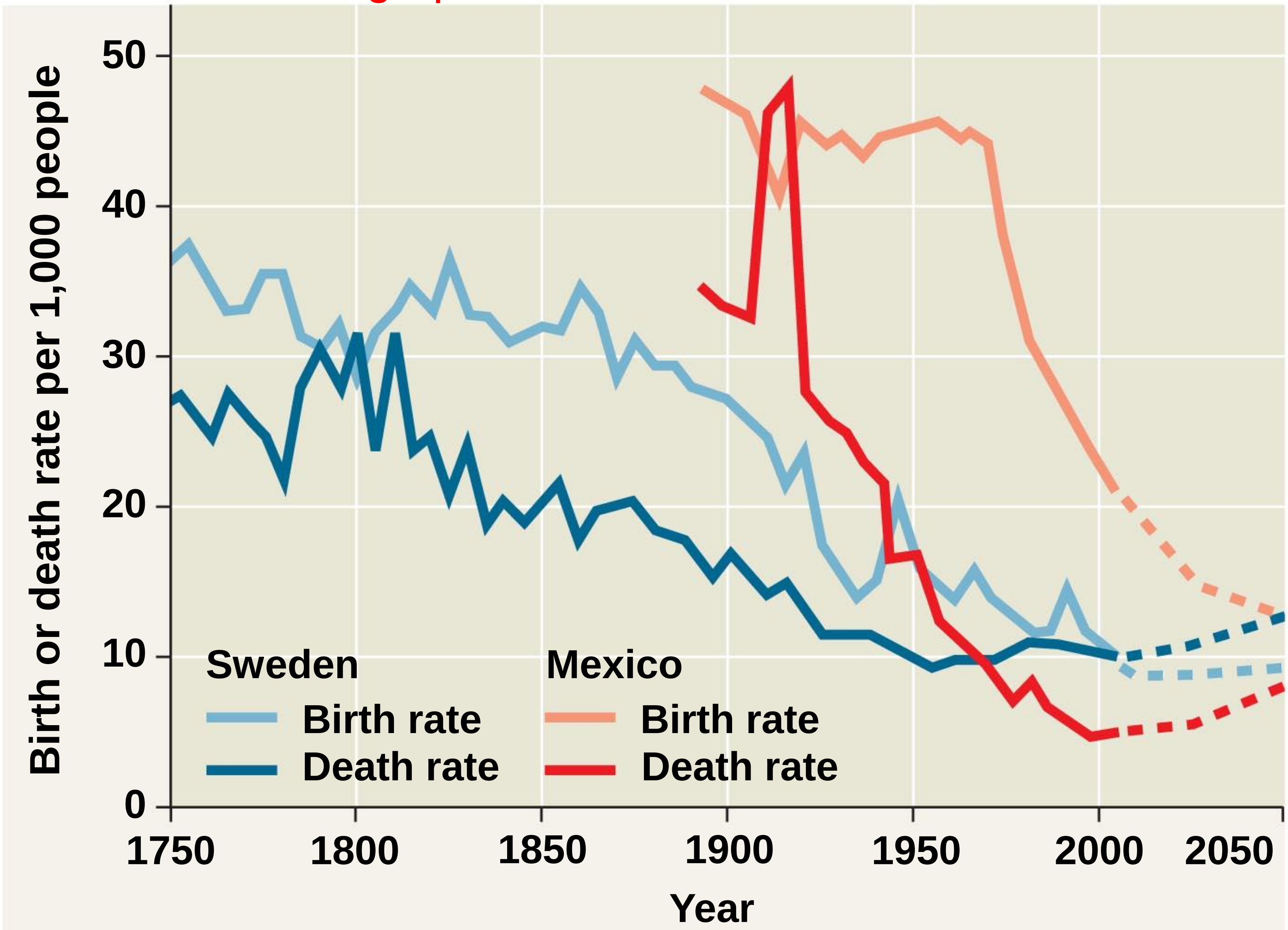


Fig. 53-25

Age-structure pyramids for the human population of three countries

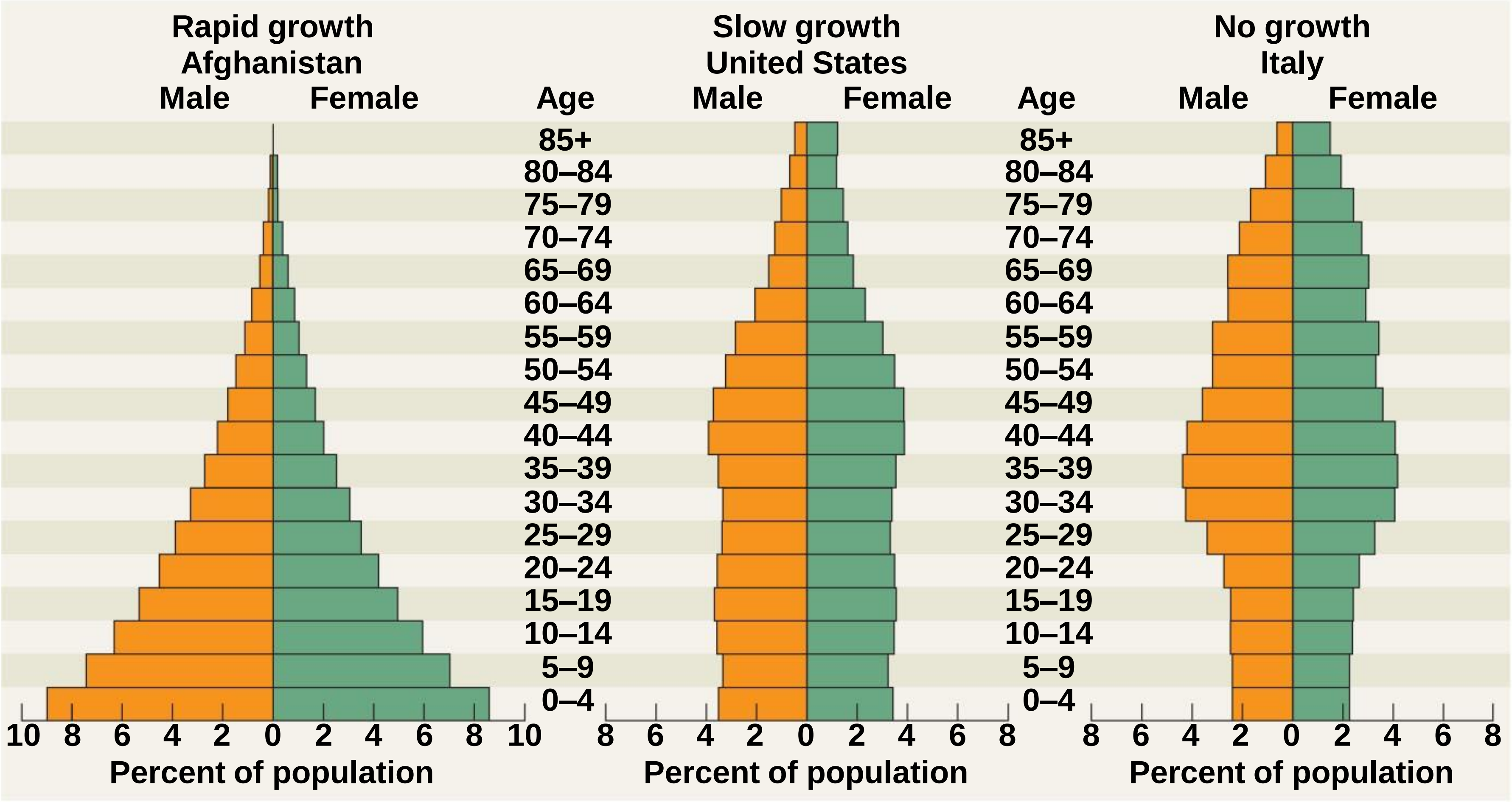
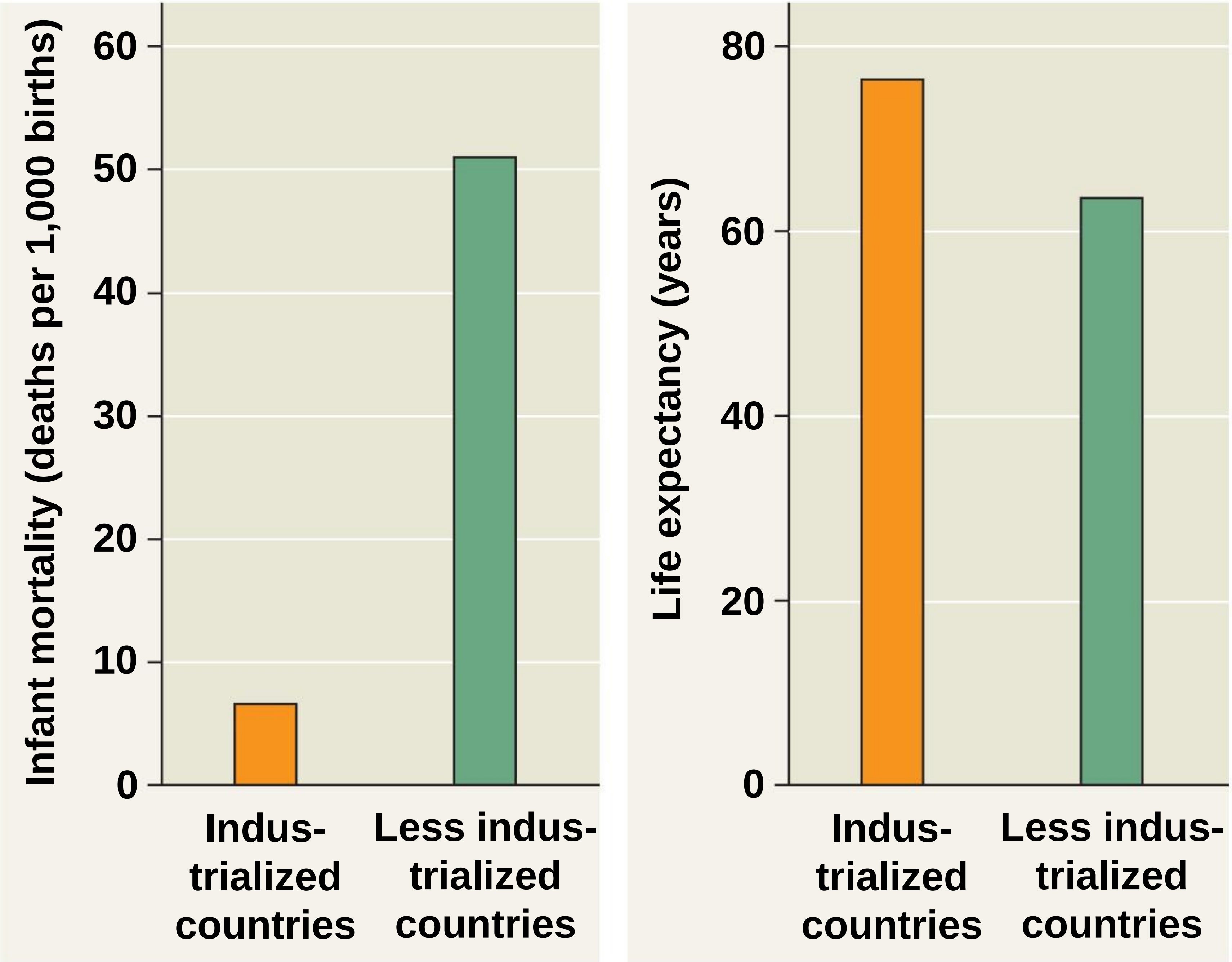


Fig. 53-26


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

Estimates of Carrying Capacity

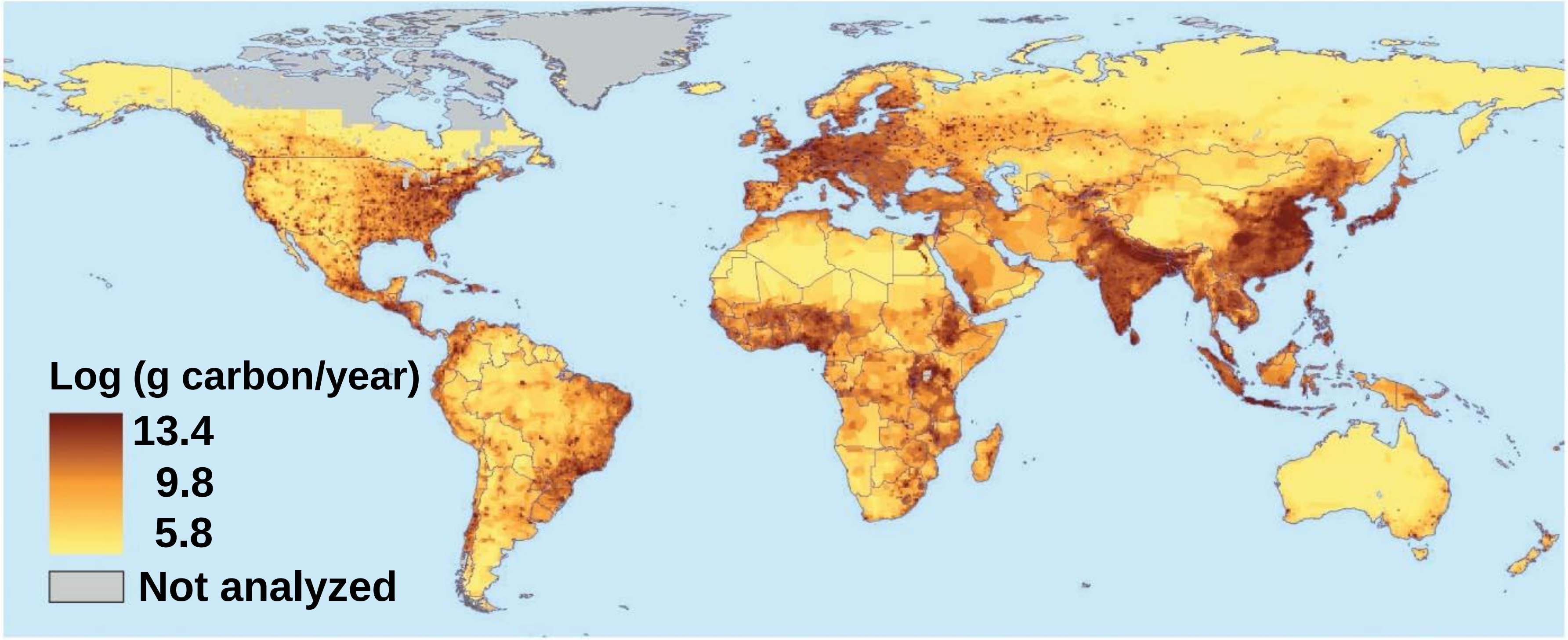
- The carrying capacity of Earth for humans is uncertain
- The average estimate is 10–15 billion

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

The amount of photosynthetic products that humans use around the world



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

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