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

$$N = \frac{sn}{x}$$
• 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

**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

• 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

**Demographics**

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

• **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.

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.

- Survivorship curves can be classified into three general types:
  - Type I: low death rates during early and middle life, then an increase in death rates 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.
- Many species are intermediate to these curves.
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

Per Capita Rate of Increase

\[ \frac{\Delta N}{\Delta t} = B - D \]

Where \( \Delta N \) is change in population size, \( \Delta t \) is time interval, \( B \) is number of births, and \( D \) is number of deaths

Table 53.2 Reproductive Table for Belding’s Ground Squirrels at Tioga Pass

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

Source: P. W. Sherman and W. L. McCann, Demography of Belding’s ground squirrels

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

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
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 as:

\[ \frac{\Delta N}{\Delta t} = bN - mN \]

The per capita rate of interest (\( r \)) 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 \( r_{\text{inst}} \) 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 \( r_{\text{max}} \).

The equation of exponential population growth is:

\[ \frac{dN}{dt} = r_{\text{max}}N \]
Exponential population growth results in a J-shaped curve.

- 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.

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 $K$.

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

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

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

*Rounded to the nearest whole number.
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

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

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
“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

![Figure 53.13](image)

**RESULTS**

<table>
<thead>
<tr>
<th>Brood Size</th>
<th>Reduced brood size</th>
<th>Normal brood size</th>
<th>Enlarged brood size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parents surviving the following winter (%)</td>
<td>100</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

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

![Dandelion](image)

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

![Brazil nut tree seeds in seed pod](image)

**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.

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

Competition for Resources

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

Toxic Wastes

- Accumulation of toxic wastes can contribute to density-dependent regulation of population size
<table>
<thead>
<tr>
<th>Predation</th>
<th>Intrinsic Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>As a prey population builds up, predators may feed preferentially on that species</td>
<td>For some populations, intrinsic (physiological) factors appear to regulate population size</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Territoriality</th>
<th>Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>In many vertebrates and some invertebrates, competition for territory may limit density</td>
<td>Population density can influence the health and survival of organisms</td>
</tr>
<tr>
<td></td>
<td>In dense populations, pathogens can spread more rapidly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population Dynamics</th>
<th>Stability and Fluctuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>The study of <strong>population dynamics</strong> focuses on the complex interactions between biotic and abiotic factors that cause variation in population size</td>
<td>Long-term population studies have challenged the hypothesis that populations of large mammals are relatively stable over time</td>
</tr>
<tr>
<td></td>
<td>Both weather and predator population can affect population size over time</td>
</tr>
<tr>
<td></td>
<td>– For example, moose on Isle Royale collapsed during a harsh winter, and when wolf numbers peaked</td>
</tr>
</tbody>
</table>
**Figure 53.18**

- **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

---

**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

---

**Regional Patterns of Population Change**

- 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

- 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.

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.
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

- 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