

The following terms are used to describe population growth:

1. The **biotic potential** is the maximum growth rate of a population under ideal conditions, with unlimited resources and without any growth restrictions. For example, some bacteria can divide every twenty minutes. At that rate, one bacterium could give rise to over a trillion bacteria in ten hours. In contrast, elephants require nearly two years for gestation of a single infant. Even at this rate, however, after two thousand years, the weight of the descendants from two mating elephants would exceed that of the earth. The following factors contribute to the biotic potential of a species:
  - Age at reproductive maturity
  - Clutch size (number of offspring produced at each reproductive event)
  - Frequency of reproduction
  - Reproductive lifetime
  - Survivorship of offspring to reproductive maturity
2. The **carrying capacity** is the maximum number of individuals of a population that can be sustained by a particular habitat.
3. **Limiting factors** are those elements that prevent a population from attaining its biotic potential. Limiting factors are categorized into density-dependent and density-independent factors, as follows:
  - **Density-dependent** factors are those agents whose limiting effect becomes more intense as the population density increases. Examples include parasites and disease (transmission rates increase with population density), competition for resources (food, space, sunlight for photosynthesis), and the toxic effect of waste products. Also, predation is frequently density-dependent. In some animals, reproductive behavior may be abandoned when populations attain high densities. In such cases, stress may be a density-dependent limiting factor.
  - **Density-independent** factors occur independently of the density of the population. Natural disasters (fires, earthquakes, volcanic eruptions) and extremes of climate (storms, frosts) are common examples.

The growth of a population can be described by the following equation:

$$r = \frac{\text{births} - \text{deaths}}{N}$$

In this equation,  $r$  is the **reproductive rate** (or **growth rate**), and  $N$  is the population size at the beginning of the interval for which the births and deaths are counted. The numerator of the equation is the net increase in individuals. If, for example, a population of size  $N = 1000$  had 60 births and 10 deaths over a one-year period, then  $r$  would equal  $(60 - 10)/1000$ , or 0.05 per year.

If both sides of the equation are multiplied by  $N$ , the equation can be expressed as follows:

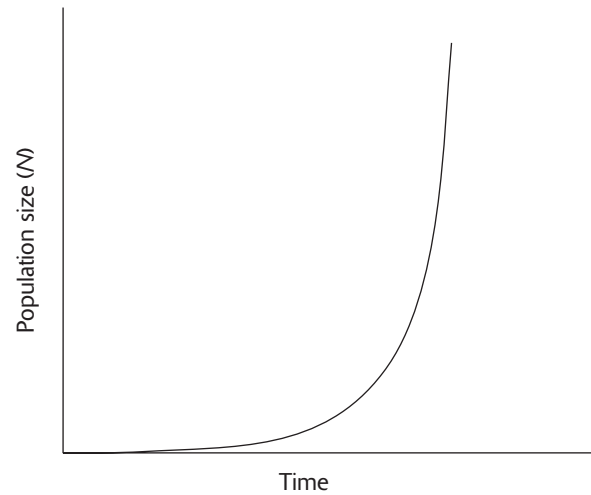
$$\frac{\Delta N}{\Delta t} = rN = \text{births} - \text{deaths}$$

The Greek letter delta ( $\Delta$ ) means “change in.” Thus,  $\Delta N/\Delta t$  means the change in the number of individuals in a given time interval.

When the reproductive rate,  $r$ , is maximum (the biotic potential), it is called the **intrinsic rate** of growth. Note, however, that when deaths exceed births,  $r$  will be negative, and the population size will decrease. On the other hand, when births and deaths are equal, the growth rate is zero and the population size remains constant (ZPG).

Population ecologists describe two general patterns of population growth, as follows:

1. **Exponential growth** occurs whenever the reproductive rate is greater than zero. On a graph where population size is plotted against time, a plot of exponential growth rises quickly, forming a **J-shaped** curve (Figure 15-3).



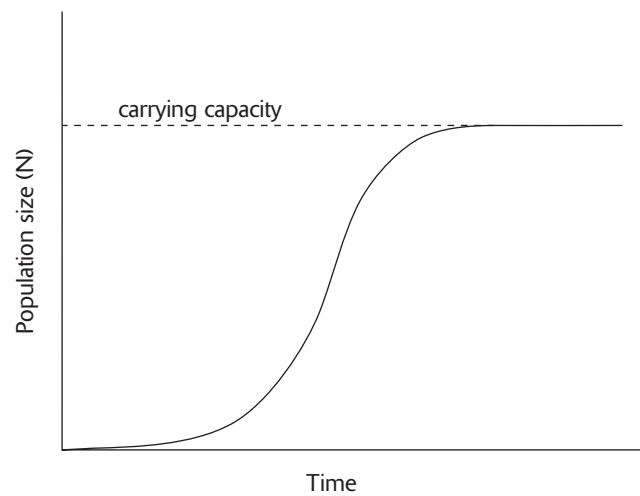
**Exponential Population Growth**

Figure 15-3

2. **Logistic growth** occurs when limiting factors restrict the size of the population to the carrying capacity of the habitat. In this case, the equation for reproductive rate given above is modified as follows:

$$\frac{\Delta N}{\Delta t} = rN \left( \frac{K - N}{K} \right)$$

$K$  represents the carrying capacity. In logistic growth, when the size of the population increases, its reproductive rate decreases until, at carrying capacity (that is, when  $N = K$ ), the reproductive rate is zero and the population size stabilizes. A plot of logistic growth forms an **S-shaped**, or **sigmoid**, curve (Figure 15-4).



**Logistic Population Growth**

Figure 15-4

**Population cycles** are fluctuations in population size in response to varying effects of limiting factors. For example, since many limiting factors are density-dependent, they will have a greater effect when the population size is large as compared to when the population is small. In addition, a newly introduced population may grow exponentially beyond

Two kinds of flow charts are often used to show the flow of energy between specific organisms. The arrows used in the flow chart indicate the direction of energy flow.

1. A **food chain** is a linear flow chart of who eats whom. For example, a food chain depicting energy flow in a savanna may look like this:

**grass → zebra → lion → vulture**

2. A **food web** is an expanded, more complete version of a food chain. It would show all of the major plants in the ecosystem, the various animals that eat the plants (such as insects, rodents, zebras, giraffes, antelopes), and the animals that eat the animals (lions, hyenas, jackals, vultures). Detritivores may also be included in the food web. Arrows connect all organisms that are eaten to the animals that eat them, that is, in the direction of energy flow.

## Biogeochemical Cycles

Biogeochemical cycles describe the flow of essential elements from the environment to living things and back to the environment. The following list outlines the major storage locations (reservoirs) for essential elements, the processes through which each element incorporates into terrestrial plants and animals (assimilation), and the processes through which each element returns to the environment (release).

1. **Hydrologic cycle** (water cycle).
  - *Reservoirs*: oceans, air (as water vapor), groundwater, glaciers. (Evaporation, wind, and precipitation move water from oceans to land.)
  - *Assimilation*: plants absorb water from the soil; animals drink water or eat other organisms (which are mostly water).
  - *Release*: plants transpire; animals and plants decompose.
2. **Carbon cycle**. Carbon is required for the building of all organic compounds.
  - *Reservoirs*: atmosphere (as  $\text{CO}_2$ ), fossil fuels (coal, oil), peat, durable organic material (cellulose, for example).
  - *Assimilation*: plants use  $\text{CO}_2$  in photosynthesis; animals consume plants or other animals.
  - *Release*: plants and animals release  $\text{CO}_2$  through respiration and decomposition;  $\text{CO}_2$  is released when organic material (such as wood and fossil fuels) is burned.
3. **Nitrogen cycle**. Nitrogen is required for the manufacture of all amino acids and nucleic acids.
  - *Reservoirs*: atmosphere ( $\text{N}_2$ ); soil ( $\text{NH}_4^+$  or ammonium,  $\text{NH}_3$  or ammonia,  $\text{NO}_2^-$  or nitrite,  $\text{NO}_3^-$  or nitrate).
  - *Assimilation*: plants absorb nitrogen either as  $\text{NO}_3^-$  or as  $\text{NH}_4^+$ ; animals obtain nitrogen by eating plants or other animals. The stages in the assimilation of nitrogen are as follows:
    - Nitrogen fixation**:  $\text{N}_2$  to  $\text{NH}_4^+$  by nitrogen-fixing prokaryotes (in soil and root nodules);  $\text{N}_2$  to  $\text{NO}_3^-$  by lightning and UV radiation.
    - Nitrification**:  $\text{NH}_4^+$  to  $\text{NO}_2^-$  and  $\text{NO}_2^-$  to  $\text{NO}_3^-$  by various nitrifying bacteria.
    - $\text{NH}_4^+$  or  $\text{NO}_3^-$  to organic compounds by plant metabolism.
  - *Release*: denitrifying bacteria convert  $\text{NO}_3^-$  back to  $\text{N}_2$  (**denitrification**); detritivorous bacteria convert organic compounds back to  $\text{NH}_4^+$  (**ammonification**); animals excrete  $\text{NH}_4^+$  (or  $\text{NH}_3$ ), urea, or uric acid.
4. **Phosphorus cycle**. Phosphorus is required for the manufacture of ATP and all nucleic acids. Biogeochemical cycles of other minerals, such as calcium and magnesium, are similar to the phosphorus cycle.
  - *Reservoirs*: rocks and ocean sediments. (Erosion transfers phosphorus to water and soil; sediments and rocks that accumulate on ocean floors return to the surface as a result of uplifting by geological processes.)
  - *Assimilation*: plants absorb inorganic  $\text{PO}_4^{3-}$  (phosphate) from soils; animals obtain organic phosphorus when they eat plants or other animals.
  - *Release*: plants and animals release phosphorus when they decompose; animals excrete phosphorus in their waste products.

Use the following key for Questions 8–13. Each answer in the key may be used once, more than once, or not at all.

- A. Character displacement
  - B. Commensalism
  - C. Mutualism
  - D. Batesian mimicry
  - E. Müllerian mimicry
- 8.** Burr-bearing seeds that are dispersed by clinging to the fur of certain birds do not harm or help the birds.
- 9.** The monarch and viceroy butterflies both have orange wings with the same distinctive black markings. When the monarch caterpillar feeds on milkweed, a toxic plant, it stores the toxins, making both the monarch caterpillar and butterfly unpalatable and toxic. The viceroy caterpillar feeds on nontoxic plants.
- 10.** The mating calls of two species of frogs are different when they occupy the same island. On separate islands, the mating calls are the same.
- 11.** Oxpeckers are birds that ride rhinoceroses and other ungulates and eat various skin parasites, such as ticks.
- 12.** Several species of poisonous snakes bear bright colors of red, black, and yellow.
- 13.** Several species of brightly colored, harmless snakes look like poisonous coral snakes.
- 14.** All of the following kinds of plants or animals characterize the initial stages of succession EXCEPT:
- A. pioneer species
  - B. *r*-selected species
  - C. species with good dispersal ability
  - D. species that can tolerate poor growing conditions
  - E. species that invest large amounts of resources or time into development of progeny

- 15.** Primary succession would occur on a
- A. meadow destroyed by flood
  - B. meadow destroyed by overgrazing
  - C. newly created volcanic island
  - D. section of a forest destroyed by an avalanche
  - E. section of a forest destroyed by fire
- 16.** All of the following increase the concentration of CO<sub>2</sub> in the atmosphere EXCEPT:
- A. photosynthesis
  - B. slash-and-burn clearing of tropical rain forests
  - C. burning of fossil fuels
  - D. burning of wood for cooking and heating
  - E. burning of gasoline
- 17.** Nitrogen becomes available to plants by all of the following processes EXCEPT:
- A. ammonification
  - B. denitrification by denitrifying bacteria
  - C. nitrification by nitrifying bacteria
  - D. nitrogen fixation in plant nodules
  - E. nitrogen fixation by soil prokaryotes
- 18.** The transition from a tropical rain forest to a savanna is marked by fewer and fewer trees. This is most likely caused by changes in
- A. temperature
  - B. rainfall
  - C. the length of the growing season
  - D. the average length of daylight
  - E. CO<sub>2</sub> concentration

Question 19 refers to the following food chain.

**dinoflagellates → oysters → humans**

- 19.** In the above food chain, oysters represent
- A. detritivores
  - B. producers
  - C. herbivores
  - D. primary carnivores
  - E. secondary consumers