Chapter 2: Population Ecology

Learning Outcomes - At the end of this section, students will be able to:

- Define the variables in the exponential and logistic growth equations.
- Use the exponential and logistic equations to predict population growth rate.
- Compare the environmental conditions represented by the exponential growth model vs. the logistic growth model.
- Define carrying capacity and be able to label the carrying capacity on a graph.
- Compare density-dependent and density-independent birth and death rates. Give examples of each.
- Interpret survivorship curves and give examples of organisms that would fit each type of curve.

Chapter outline

1. What is population ecology?
3. Exponential growth.
4. Logistic growth.
5. Density-dependent and independent rates.

What is population ecology?

A population can be generally defined as a group of individuals of the same species occupying a given area at a given time. Populations change over time. Populations grow and shrink and the age and gender composition also change through time and in response to changing environmental conditions. Population ecology is the study of populations and their changes over time.

Population Size and Density

The study of any population usually begins by determining how many individuals of a particular species exist, and how closely associated they are with each other. Within a particular habitat, a population can be characterized by its population size (N), defined by the total number of individuals, and its population density, the number of individuals within a specific area or volume. Population size and density are the two main characteristics used to describe a population. For example, populations with more individuals may be more stable than smaller populations based on their genetic variability, and thus their potential to adapt to the environment. Alternatively, a member of a population with low population density (more spread
out in the habitat), might have more difficulty finding a mate to reproduce compared to a population of higher density.

**Exponential Growth**

Charles Darwin, in his theory of natural selection, was greatly influenced by the English clergyman Thomas Malthus. Malthus published a book (An Essay on the Principle of Population) in 1798 stating that populations with unlimited natural resources grow very rapidly. This accelerating pattern of increasing population size is called **exponential growth**. According to the Malthus model, once population size exceeds available resources, population growth decreases dramatically.

The best example of exponential growth is seen in bacteria. Bacteria are prokaryotes that reproduce by prokaryotic fission. This division takes about an hour for many bacterial species. If 100 bacteria are placed in a large flask with an unlimited supply of nutrients (so the nutrients will not become depleted), after an hour, there is one round of division and each organism divides, resulting in 200 organisms - an increase of 100. In another hour, each of the 200 organisms divides, producing 400 - an increase of 200 organisms. After the third hour, there should be 800 bacteria in the flask - an increase of 400 organisms. The important concept of exponential growth is that the **population growth rate** (dN/dt) the number of organisms added in each reproductive generation—is accelerating; that is, it is increasing at a greater and greater rate. After ½ a day and 12 of these cycles, the population would have increased from 100 to more than 24,000. When the population size, N, is plotted over time, a J-shaped growth curve is produced (Figure 2.1).

![Figure 2.1: The “J” shaped curve of exponential growth for a hypothetical population of bacteria. The population starts out with 100 individuals and after 11 days there are over 24,000 individuals. As time goes on and the population size increases, the rate of increase also increases (each step up becomes bigger). In this figure “r” is positive.](image)
This is the equation for exponential population growth:

\[
\frac{dN}{dt} = rN
\]

\[
\frac{dN}{dt} = \text{population growth rate}
\]

\[
r = \text{per capita rate of increase}
\]

\(dN/dt\) is the population growth rate, it is the change in population size over the change in time. The population growth rate \((dN/dt)\) depends on population size \((N)\) and the per capita rate of increase \((r)\). “\(r\)” is the per capita rate of increase, and it is equal to the birth rate subtracted from the death rate for a population. “\(r\)” can be positive, meaning the population is increasing in size; or negative, meaning the population is decreasing in size; or zero, where population size is unchanging, a condition known as zero population growth. “\(r\)” varies depending on the organism, for example a population of bacteria would have a much higher “\(r\)” than an elephant population. In the exponential growth model, population size is multiplied by the per capita rate of increase. So a larger population size (larger \(N\)) will result in a larger population growth rate.

**Logistic Growth**

Exponential growth cannot continue forever because resources (food, water, shelter) will become limited. Exponential growth may occur in environments where there are few individuals and plentiful resources, but when the number of individuals gets large enough, resources will be depleted, slowing the growth rate. When resources are limited, populations exhibit logistic growth.

In logistic growth, population growth rate decreases as resources become scarce. When the population size equals the carrying capacity of the environment, population growth rate levels off at zero, resulting in the logistic growth curve (Figure 2.2). This population size, which represents the maximum population size that a particular environment can support, is called the **carrying capacity**, or \(K\).
**Figure 2.2:** Shows logistic growth of a hypothetical bacteria population. The population starts out with 10 individuals and then reaches the carrying capacity of the habitat which is 500 individuals.

This is the equation for the logistic growth model:

\[
\frac{dN}{dt} = rN \left( 1 - \frac{N}{K} \right)
\]

- **N** = population size
- \( \frac{dN}{dt} \) = population growth rate
- **r** = per capita rate of increase
- **K** = carrying capacity

In the logistic growth model, a population starts out small with plenty of resources; the population size is much lower than the carrying capacity of the environment. Population size increases and population growth rate initially increases. But then as population size grows larger resources become more limited and population growth rate begins to slow down. When the population size is at the carrying capacity of the environment (\( N = K \)) then population growth rate is zero and the population stays at a constant size.

Yeast, a microscopic fungus used to make bread and alcoholic beverages, exhibits the classical S-shaped logistic growth curve when grown in a test tube (Figure 2.3). Its growth levels off as the population depletes the nutrients that are necessary for its growth. In the real world, however, there are variations to this idealized curve. For example, a population of harbor seals may exceed the carrying capacity for a short time and then fall below the carrying capacity. This fluctuation in population size continues to occur as the population oscillates around its carrying capacity. Still, even with this oscillation, the logistic model is exhibited.
Figure 2.3: Graph (a) plots amount of yeast versus time of growth in hours. The curve rises steeply, and then plateaus at the carrying capacity. Data points tightly follow the curve. Graph (b) plots the number of harbor seals versus time in years. Again, the curve rises steeply then plateaus at the carrying capacity, but this time there is much more scatter in the data. A micrograph of yeast cells, which are oval in shape, and a photo of a harbor seal are shown.

Density-dependent and density-independent rates

Population size can be affected by density-dependent factors, in which the density of the population at a given time affects birth and death rates, and density-independent factors, which influence population size regardless of population density. Conservation biologists want to understand both types because this helps them manage populations and prevent extinction or overpopulation.

Density-dependent birth rates and death rates depend on the population size. Most density-dependent factors are biological in nature (biotic), and include predation, inter- and intraspecific competition, accumulation of waste, and diseases such as those caused by parasites. Usually, higher population density results in higher death rates and lower birth rates. For example, as a population increases in size food becomes scarcer and some individuals will die from starvation meaning that the death rate from starvation increases as population size increases. Also as food becomes scarcer, birth rates decrease due to fewer available resources for the mother meaning
that the birth rate decreases as population size increases. For density-dependent factors, there is a feedback loop between population density and the density-dependent factor.

An example of density-dependent regulation is shown in Figure 2.4 with results from a study focusing on the giant intestinal roundworm (*Ascaris lumbricoides*), a parasite of humans and other mammals. Denser populations of the parasite exhibited lower fecundity (fewer eggs). One possible explanation for this is that females would be smaller in more dense populations because of limited resources and smaller females produce fewer eggs.

![Fecundity as a Function of Population](image)

**Figure 2.4:** Graph of fecundity, which is the number of eggs per female, as a function of population size. The number of eggs decreases rapidly at first, then levels off between 30 to 50 worms. In this population of roundworms, fecundity (number of eggs) decreases with population density.

Density-independent birth rates and death rates do NOT depend on population size; these factors are independent of, or not influenced by, population density. Many factors influence population size regardless of the population density, including weather, natural disasters, pollution and other abiotic factors. For example, an individual deer may be killed in a forest fire regardless of how many deer happen to be in the forest. The forest fire is not responding to deer population size. As the weather grows cooler in the winter, many insects die from the cold. This doesn’t change whether there is a population size of 100 mosquitoes or 100,000 mosquitoes, most mosquitoes will die from the cold regardless of the population size and the weather will change irrespective of mosquito population density.

In real-life situations, density-dependent and independent factors interact. For example, a devastating earthquake occurred in Haiti in 2010. This earthquake was a natural geologic event that caused a high human death toll from this density-independent event. Then there were high densities of people in refugee camps and the high density caused disease to spread quickly, representing a density-dependent death rate.
Survivorship Curves

We can compare different species, or populations within the same species, by comparing survivorship curves. Survivorship curves summarize patterns of survival over time. A survivorship curve plots age along the x-axis and number of survivors, or % surviving, along the y-axis. All survivorship curves start along the y-axis intercept with all of the individuals in the population (or 100% of the individuals surviving). As the population ages, individuals die and the curves go down. A survivorship curve never goes up.

Survivorship curves generally fall into one of three typical shapes, Types I, II and III (Figure 2.5). Organisms that exhibit **Type I** survivorship curves have the highest probability of death in old age. In Type I survivorship curves, juvenile survivorship is high and most mortality (death) occurs during old age. Humans are an example of a species with a Type I survivorship curve. Elephants are another example. Many species that have few offspring and lots of parental care are species with a Type I survivorship curve. Species with **Type III** survivorship patterns have the greatest probability of death at young ages. In Type III survivorship curves, juvenile survivorship is very low and many individuals die young. However, any individuals that make it to maturity are likely to live long time. Dandelions are an example of a species with a Type III survivorship curve. Many frogs also fit this pattern. A female frog may lay hundreds of eggs in a pond and these eggs produce hundreds of tadpoles. However, predators eat many of the young tadpoles and competition for food also means that many tadpoles don’t survive. But the few tadpoles that do survive and metamorphose into adults then live for a relatively long time (for a frog). **Type II** survivorship is intermediate between the others and suggests that such species have an even chance of dying at any age. Many birds and small reptiles, like lizards, have a Type II survivorship curve.

![Survivorship Curve Diagram](Image)
**Figure 2.5:** Survivorship curves show the distribution of individuals in a population according to age. Humans and most mammals have a Type I survivorship curve because death primarily occurs in the older years. Birds have a Type II survivorship curve, as death at any age is equally probable. Trees have a Type III survivorship curve because very few survive the younger years, but after a certain age, individuals are much more likely to survive.

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This material has been modified from the OpenStax Biology textbook.