

Chapter 2: Population Ecology and Human Demography



Sandhill cranes (*Grus canadensis*) congregate in a wetland habitat during migration, silhouetted against the warm hues of sunrise. Image credit: Unknown author, Microsoft Stock Images.

Learning Outcomes

By the end of this chapter, students will be able to:

1. Use the exponential and logistic equations to predict population growth rate.
2. Compare the environmental conditions represented that apply to the exponential growth model vs. the logistic growth model.
3. Define carrying capacity and be able to identify it on a graph.
4. Identify density-dependent and density-independent factors that limit population growth.
5. Interpret survivorship curves and give examples of organisms that fit each type of curve.
6. Explain historical, current, and future human population growth trends and their consequences.
7. Interpret age-structure diagrams.
8. Explain the demographic transition and what happens to birth rates, death rates, population growth rate, and population size as a country moves through the stages of the demographic transition model.
9. Name examples of countries in the different stages of the demographic transition models and match age-structure diagrams with the stages of the demographic transition model.
10. Define life expectancy and total fertility rate and explain how each one changes as a country moves through the demographic transition model.

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2.1 What is Population Ecology?

Ecology is a sub-discipline of biology that studies the interactions between organisms and their environments. A **population** is a group of interbreeding individuals (individuals of the same species) living and interacting in a given area at a given time. These individuals rely on the same resources and are influenced by the same environmental factors. **Population ecology**, therefore, is the study of how individuals of a particular species interact with their environment and change over time. 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. A population can be characterized by its **population size** (N), defined as the total number of individuals, and its **population density**, the number of individuals of a particular species within a specific area or volume (units are number of individuals/unit area or unit volume). Population *size* and *density* are the two main characteristics used to describe a population. For example, larger populations may be more stable and able to persist better than smaller populations because of the greater amount of genetic variability, and their potential to adapt to the environment or to changes in the environment. On the other hand, a member of a population with a low population density (more spread out in the habitat) will have access to adequate food and space but might have more difficulty finding a mate to reproduce. Other characteristics of a population include **dispersion** – the way individuals are spaced within the area; **age structure** – number of individuals in different age groups; **sex ratio** – proportion of males to females; and **growth** – change in population size (increase or decrease) over time.

2.2 Population Growth Models

Populations change over time and space as individuals are added through birth or **immigration** (arrive from outside the population) and others die or **emigrate** (depart from the population to another location). Populations grow and shrink and the age and gender composition also change through time and in response to changing environmental conditions. Some populations, for example trees in a mature forest, are relatively constant over time while others, such as deer utilizing the forest, change frequently. Using idealized **models**, population ecologists can predict how the size of a particular population will change over time under different conditions.

2.2.1 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 but once population size exceeds available resources, population growth decreases dramatically. This accelerating pattern of increasing population size is called **exponential growth**, meaning that the population is increasing by a fixed percentage each year. When plotted (visualized) on a graph showing how the population size increases over time, the result is a J-shaped curve (**Figure 2.1**).

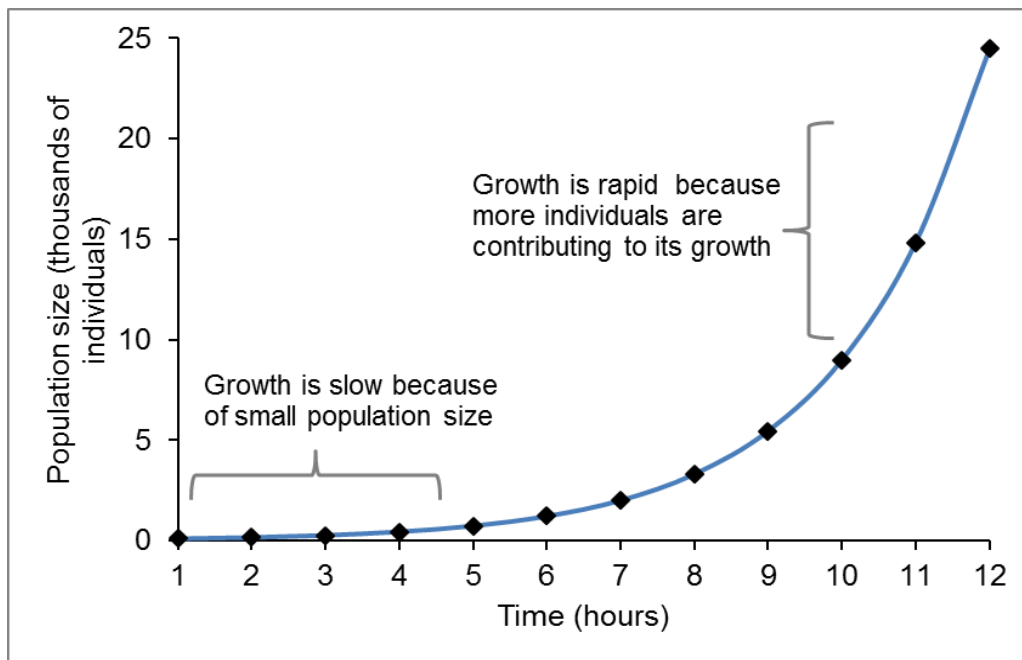


Figure 2.1: The “J” shaped curve of exponential growth for a hypothetical population of bacteria. The population starts out with 100 individuals and after 11 hours there are over 24,000 individuals. As time goes on and the population size increases, the rate of increase also increases (each step up becomes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

Each member of a population contributes to the population’s growth by a certain amount (r) and as the population gets larger, there are more individuals contributing to growth by that same amount (the fixed percentage). In nature, exponential growth only occurs if there are no external limits such as food, space, and enemies.

One example of exponential growth is seen in bacteria. Bacteria are prokaryotes (organisms whose cells lack a nucleus and other membrane-bound organelles) that reproduce by binary fission (each individual cell splits into two new cells). This process of reproduction 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 fission 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. After $\frac{1}{2}$ a day and 12 of these cycles, the population would have increased from 100 cells to more than 24,000 cells. When the population size, N , is plotted over time, a J-shaped growth curve is produced (**Figure 2.1**). This shows that the number of individuals added during each reproduction generation is accelerating – increasing at a faster rate.

This type of growth can be represented with a mathematical function known as the **exponential growth model**:

$$G = r * N \text{ (or } G = rN, \text{ also } dN/dt = rN).$$

In this equation

G (or dN/dt) is the *population growth rate*; it refers to the number of individuals added to the population per time interval time.

r is the *per capita rate of increase* (also referred to as *per capita growth rate*). It refers to the average contribution toward the population's growth made by each individual in a population; per capita means “per person” (see more in **Box 2.1**).

N is the *population size*, the number of individuals in the population at a particular time.

2.2.2 Logistic Growth

Exponential growth cannot continue indefinitely because resources (food, water, shelter) will become limited. Exponential growth may occur in environments where there are few individuals and plentiful resources, but soon or later, the population gets large enough that individuals run out of vital resources such as food or living space, slowing the growth rate. Most natural populations exhibit what we call **logistic growth**. In logistic growth a population grows nearly exponentially at first when the population is very small and resources are plentiful but growth rate slows down as the population size gets close to the limit of the environment and resources begin to be in short supply. In logistic growth, the population size finally stabilizes (zero population growth rate) at the maximum population size that can be supported by the environment (**carrying capacity**). This means that the amount of individuals added to the population equals the amount removed, which keeps the population size the same (stable). This results in a characteristic S- shaped growth curve (**Figure 2.2**). The mathematical function or logistic growth model is represented by the following equation:

Box 2.1 Per capita rate of increase (r)

In exponential growth, *population growth rate* (G) depends on population size (N) and the *per capita rate of increase* (r). In this model r does not vary (it is a fixed percentage) so any change in population growth rate, G , is caused by the change in the size of the population, N . As new individuals are added to the population, each of the new additions also contributes to population growth at the same rate (r) as the individuals that were already in the population.

$$r = (\text{birth rate} + \text{immigration rate}) - (\text{death rate and emigration rate}).$$

If r is positive ($> \text{zero}$), the population is increasing in size; this means that more individuals are added through birth and immigration than are removed by death and emigration.

If r is negative ($< \text{zero}$), the population is decreasing in size; this means that the amount of individuals added to the population through birth and immigration is less than the amount removed through death and emigration.

If r is zero, then the population growth rate (G) is zero and population size is not changing, a condition known as zero population growth. “ r ” varies depending on the type of organism, for example a population of bacteria would have a much higher “ r ” than a population of elephants. In the exponential growth model r is multiplied by the population size, N , so population growth rate is largely influenced by N . This means that if two populations have the same per capita rate of increase (r), the population with a larger N will have a larger population growth rate than the one with a smaller N .

$$G = r * N * \left[1 - \frac{N}{K} \right]$$

In this equation, G , r , N are the same as in the exponential growth model.

K is the *carrying capacity* – the maximum population size that a particular environment can support or sustain (“carry”).

In the exponential growth model, population growth rate is mainly dependent on N so that each new individual that is added to the population contributes equally to the growth of the population as those individuals previously in the population because per capita rate of increase is fixed. In the logistic growth model, an individual’s contribution to population growth rate depends on the amount of resources available (K). As the number of individuals (N) in a population increases, fewer resources are available to

each individual. As resources diminish, each individual on average, produces fewer offspring than when resources are plentiful, causing the birth rate of the population to decrease (see more in **Box 2.2**).

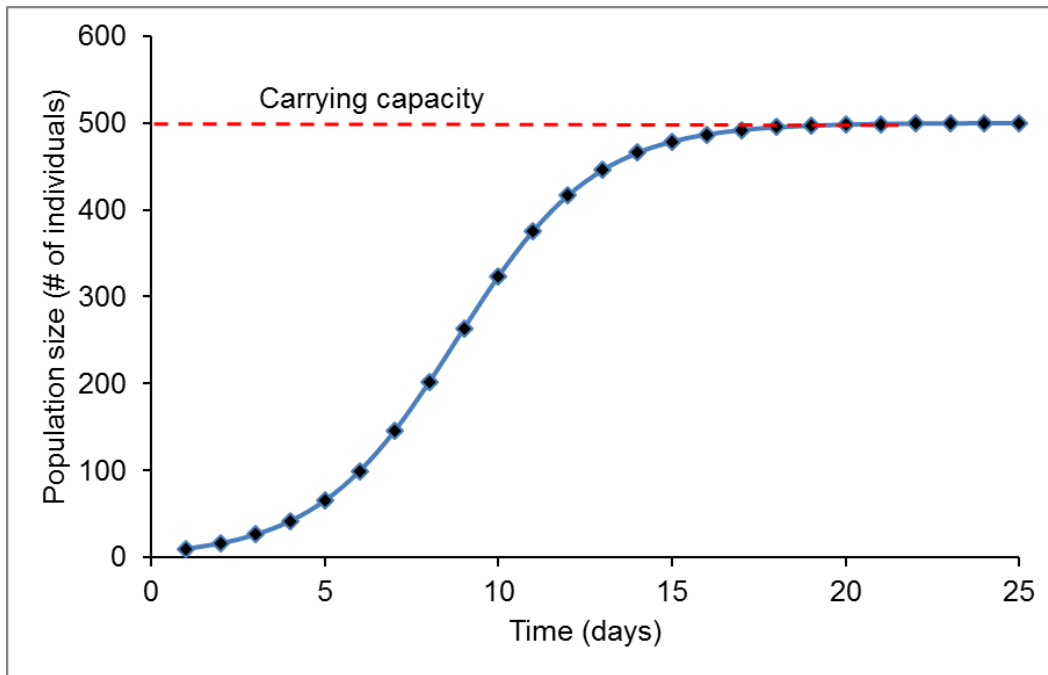


Figure 2.2: Shows logistic growth of a hypothetical bacteria population. The population starts out with 10 individuals and then reaches the carrying capacity of the habitat, which is 500 individuals.

An S-shaped curve such as the one in **Figure 2.2** is the idealized curve of logistic growth but most natural populations do not exhibit population sizes that fall perfectly along this curve. 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**). Notice that the points representing population size at different time intervals do not all fall perfectly along the line but most are on or very close to the line. As the population grows, nutrients needed for growth become depleted and growth levels off. In the real world, however, there are variations to this idealized curve. For example, a population of harbor seals may actually exceed the carrying capacity for a short time, causing resources to be unable to support the population. This overshoot of the carrying capacity would cause the population fall below the carrying capacity for a brief time period and as more resources become available, the population grows again (**Figure 2.4**). This fluctuation in population size continues to occur as the population oscillates/cycles around its carrying capacity. Still, even with this oscillation, the logistic model is exhibited.

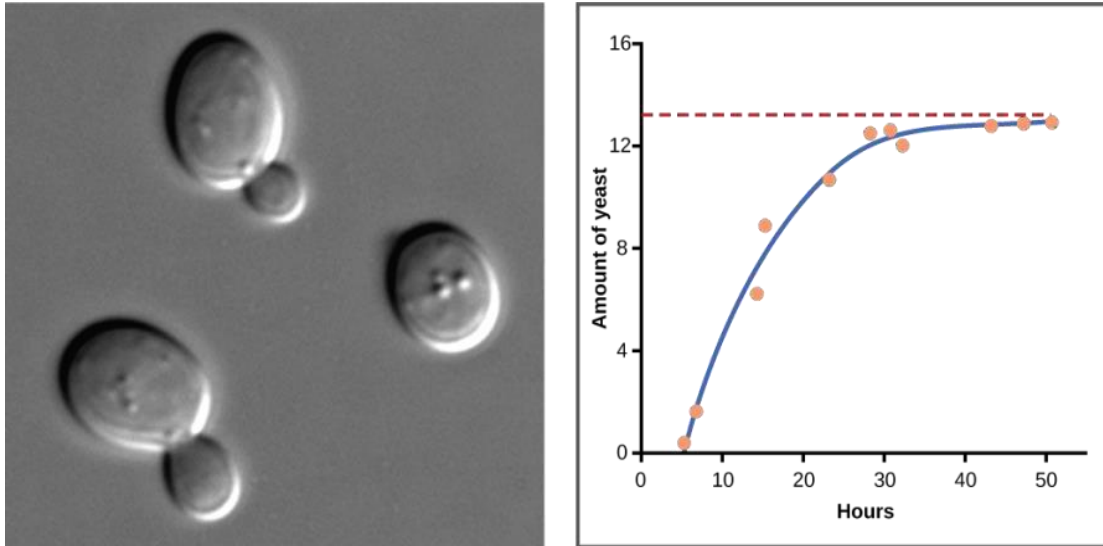


Figure 2.3: Graph showing amount of yeast versus time of growth in hours. The curve rises steeply, and then plateaus at the carrying capacity. Data points tightly follow the curve. The image is a micrograph (microscope image) of yeast cells.

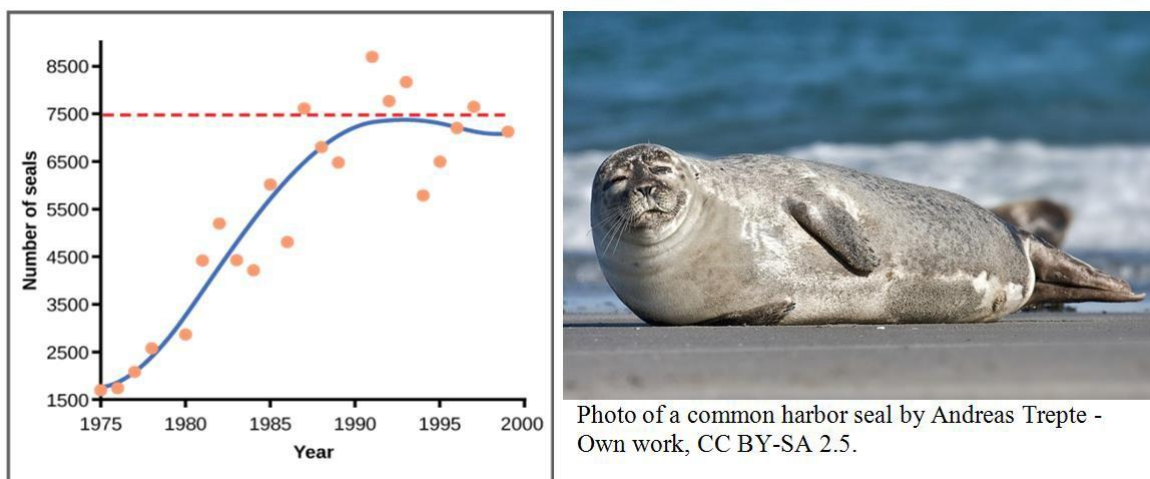


Figure 2.4: Graph showing the number of harbor seals versus time in years. The curve rises steeply then plateaus around the point that represents the carrying capacity of its habitat. Notice how there is much more scatter in the data than what was exhibited in the yeast example above. Photo of a common harbor seal was obtained from <https://commons.wikimedia.org/w/index.php?curid=21012232>.

Box 2.2 How K influences the population growth rate

In the logistic growth model, the exponential growth ($r * N$) is multiplied by fraction or expression $(1 - N/K)$ that describes the effect that limiting factors have on an increasing population. Notice that this expression is a fraction that depends on the population size (N) because the carrying capacity (K) is assumed to be fixed.

Initially when the population is very small compared to the capacity of the environment (K), $1 - N/K$ is a large fraction that nearly equals 1 so population growth rate is close to the exponential growth ($r * N$). For example, supposing an environment can support a maximum of 100 individuals and $N = 1$, N is so small that $1 - N/K$ ($1 - 1/100 = 0.99$) will be large, close to 1.

As the population increases and population size gets closer to carrying capacity (N nearly equals K), then $1 - N/K$ is a small fraction that nearly equals zero and when this fraction is multiplied by $r * N$, population growth rate is slowed considerably. In the earlier example, if the population grows to 98 individuals, which is close to (but not equal) K , then $1 - N/K$ ($1 - 98/100 = 0.02$) will be so small, close to zero.

If population size equals the carrying capacity, $N/K = 1$, so $1 - N/K = 0$, population growth rate will be zero (in the above example, $1 - 100/100 = 0$).

This model, therefore, predicts that a **population's growth rate will be small when the population size is either small or large, and highest when the population is at an intermediate level relative to K .** At small populations, growth rate is limited by the small number of individuals (N) available to reproduce and contribute to population growth rate. At large populations, growth rate is restricted by the limited amount of resources available to each of the large number of individuals to enable them to reproduce successfully. In fact, maximum population growth rate (G) occurs when N is half of K . In our example above, maximum G occurs when $N=50$.



Test your knowledge...

Population Growth

1. *At what point would population growth be highest in a population exhibiting logistic growth?*
2. *How would this differ in a population experiencing exponential growth?*
3. *Why is population growth often linked to excess resource consumption?*

2.3 Factors that Limit Population Growth

Recall previously that we defined density as the number of individuals per unit area. In nature, a population that is introduced to a new environment or is rebounding from a catastrophic decline in numbers may grow exponentially for a while because density is low and resources are not limiting. Eventually, one or more environmental factors will limit population growth rate as the population size approaches the carrying capacity and density increases. Example: imagine that in an effort to preserve elk, a population of 20 individuals is introduced to a previously unoccupied island that's 200 km² in size. The population density of elk on this island is 0.1 elk/km² (or 10 km² for each individual elk). As this population grows (depending on its per capita rate of increase), the number of individuals increases but the amount of space remains the same so density increases. Suppose that 10 years later, the elk population has grown to 800 individuals, density = 4 elk/ km² (or 0.25 km² for each individual). The population growth rate will be limited by various factors in the environment. For example, birth rates may decrease due to limited food or death rate increase due to rapid spread of disease as individuals encounter one another more often.

This impact on birth and death rate in turn influences the per capita rate of increase and how the population size changes with changes in the environment. When birth and death rates of a population vary depending on the density of the population, the rates are said to be density- dependent and the environmental factors that affect birth and death rates are known as **density- dependent factors**. Population sizes can also be held in check by factors that are not related to the density of the population and are called **density-independent factors** and 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.

The density of a population can enhance or diminish the impact of *density-dependent* factors. Most density-dependent factors are *biological* in nature (biotic), and include such things as predation, inter- and intraspecific competition for food and mates, 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 more scarce 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.

Two examples of density-dependent regulation are shown in **Figure 2.5**. First one is showing results from a study focusing on the giant intestinal roundworm (*Ascaris lumbricoides*), a parasite that infects humans and other mammals. Denser populations of the parasite exhibited lower fecundity (number of eggs per female). 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. The second one is the great tits bird, again showing that as the number of breeding bird pairs increases, the clutch size (number of eggs laid in a single brood by a nesting pair of birds) decreases.

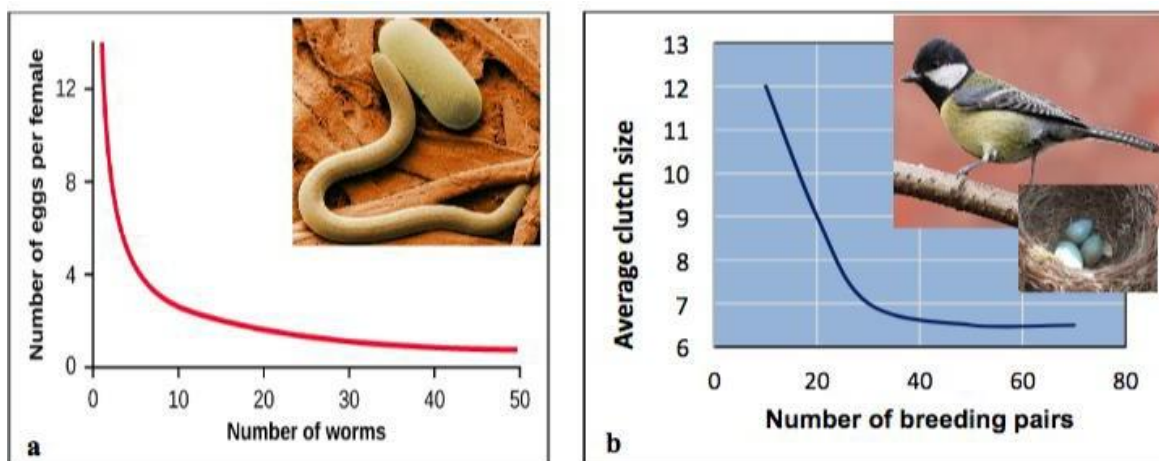


Figure 2.5: (a) Graph of number of eggs per female (fecundity), as a function of population size. In this population of roundworms, fecundity (number of eggs) decreases with population density. (b) Graph of clutch size (number of eggs per “litter”) of the great tits bird as a function of population size (breeding pairs). Again, clutch size decreases as population density increases. (Photo credits: Worm image from Wikimedia commons, public domain image; bird image from Wikimedia commons, photo by Francis C. Franklin / CC-BY-SA-3.0)

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 extremes, natural disasters (earthquakes, hurricanes, tornadoes, tsunamis, etc.), pollution and other physical/abiotic factors. For example, an individual deer or hundreds of deer may be killed in a forest fire regardless of how many deer there are in the forest. The forest fire is not responding to deer population size.

Weather changing from warm summer to cold winter is likely to kill many insects. The change in weather does not depend on whether the population size is 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 population density. Looking at the growth curve of such a population would show something like an exponential growth followed by a rapid decline rather than leveling off (**Figure 2.6**).

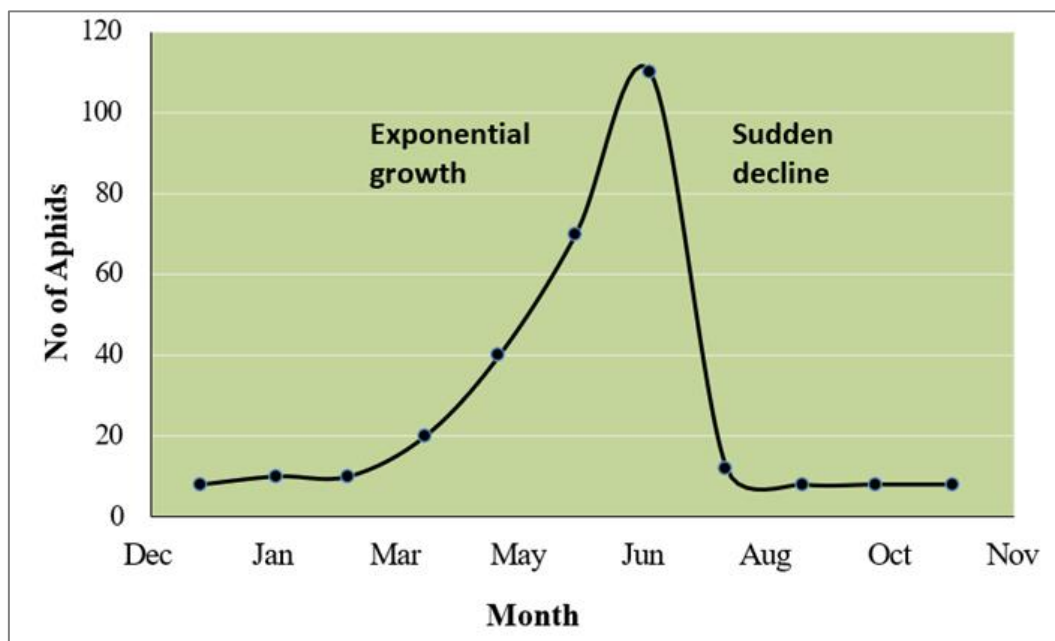


Figure 2.6: Weather change acting as a density-independent factor limiting aphid population growth. This insect population undergoes exponential growth in the early spring and then rapidly dies off when the weather turns hot and dry in the summer.

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.



Test your knowledge...

Can you think of other examples of density-dependent (biological) and density-independent (abiotic) population limiting factors?

2.4 Life Tables and Survivorship

Population ecologists use life tables to study species and identify the most vulnerable stages of organisms' lives to develop effective measures for maintaining viable populations. Life tables, like **Table 2.1**, track **survivorship**, the chance of an individual in a given population surviving to various ages. **Life tables** were invented by the insurance industry to predict how long, on average, a person will live. Biologists use a life table as a quick window into the lives of the individuals of a population, showing how long they are likely to live, when they'll reproduce, and how many offspring they'll produce. Life tables are used to construct **survivorship curves**, which are graphs showing the proportion of individuals of a particular age that are now alive in a population.

Survivorship (chance of surviving to a particular age) is plotted on the y-axis as a function of age or time on the x-axis. However, if the percent of maximum lifespan is used on the x-axis instead of actual ages, it is possible to compare survivorship curves for different types of organisms. For example, if an organism has a maximum lifespan of 20 years, 50% of its lifespan is 10 years. If another organism's maximum lifespan is 100 years, 50% of this organism's lifespan is 50 years. It would be challenging to compare these two organisms on the same graph using their absolute ages. However, when presented as percent of maximum lifespan, then the two can be plotted on the same graph because 50% means the same thing for both organisms. 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 goes down. A survivorship curve never goes up.

Table 2.1: Abbreviated Life Table for the U.S. population in 2022 showing the number who are expected to be alive at the beginning of each age based on the death rates in 2022. For example, 93,010 people out of 100,000 are expected to live to age 50 (0.996 chance of survival). The chance of surviving to age 60 is 0.991 but the chance of surviving to age 90 is only 0.867.

Age (years)	Number Living at Start of Age Interval	Number Dying During Interval	Chance of Surviving Interval	Chance of Dying During Interval
1	100000	560	0.994395	0.005605
10	99275	10	0.999895	0.000105
20	98962	75	0.999244	0.000756
30	97708	164	0.998409	0.001591
40	95954	237	0.997531	0.002469
50	93010	393	0.995774	0.004226
60	87475	822	0.990608	0.009392
70	75186	1517	0.981176	0.018824
80	54964	2794	0.954753	0.045247
90	25837	3435	0.867054	0.132946
100	2258	744	0.67035	0.329650
Over 100	1513	1513	0	1.000000

SOURCE: CDC/NCHS, National Vital Statistics System.

Survivorship curves reveal a great deal of information about a population, such as whether most offspring die shortly after birth or whether most survive to adulthood and likely to live long lives. They generally fall into one of three typical shapes, Types I, II and III (**Figure 2.7a**).

Organisms that exhibit **Type I** survivorship curves have the highest probability of surviving every age interval until old age, then the risk of dying increases dramatically. Humans are an example of a species with a Type I survivorship curve. Others include

the giant tortoise and most large mammals such as elephants. These organisms have few natural predators and are, therefore, likely to live long lives. They tend to produce only a few offspring at a time and invest significant time and effort in each offspring, which increases survival.

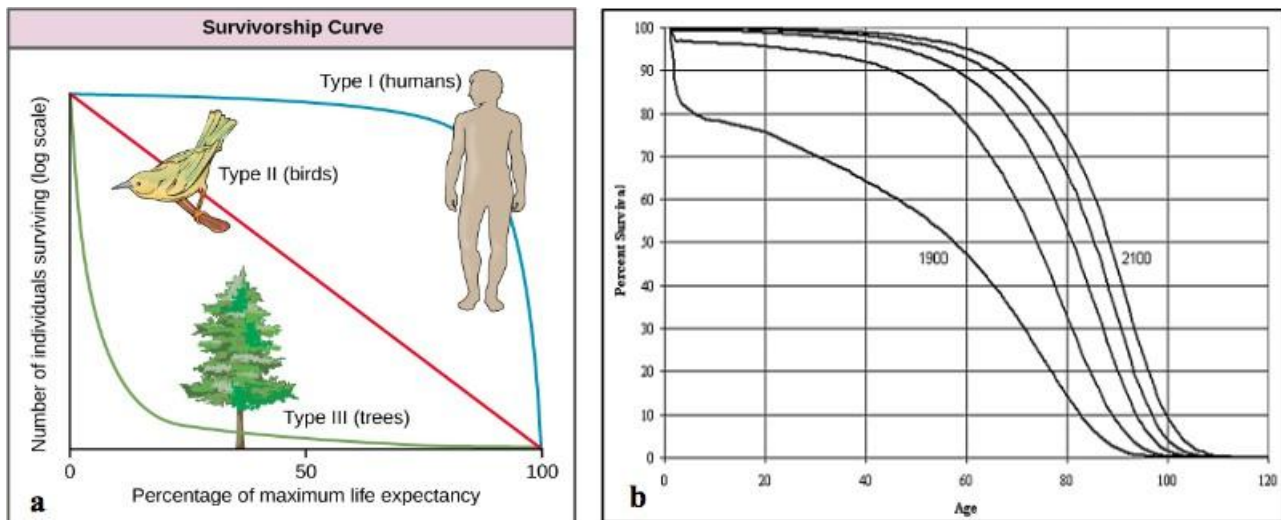


Figure 2.7: (a) Survivorship curves show the distribution of individuals in a population according to age. Humans and most large mammals have a Type I survivorship curve because most death occurs in the older years. Birds have a Type II survivorship curve, as death at any age is equally probable. Trees 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. (b) Survivorship curves for the US population for 1900, 1950, 2000, 2050, 2100. Source: https://www.ssa.gov/oact/NOTES/pdf_studies/study120.pdf (p. 16)

In **Type III** survivorship curve, most of the deaths occur in the youngest age groups. Juvenile survivorship is very low and many individuals die young but individuals lucky enough to survive the first few age intervals are likely to live a much longer time. Most plant species, insect species, frogs as well as marine species such as oysters and fishes have a Type III survivorship curve. 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). The mackerel fish, a female is capable of producing a million eggs and on average only about 2 survive to adulthood. Organisms with this type of survivorship curve tend to produce very large numbers of offspring because most will not survive. They also tend not to provide much parental care, if any.

Type II survivorship is intermediate between the others and suggests that such species have an equal chance of dying at any age. Many birds, small mammals such as squirrels, and small reptiles, like lizards, have a Type II survivorship curve. The straight line indicates that the proportion alive in each age interval drops at a steady, regular pace. The likelihood of dying in any age interval is the same.

In reality, most species don't have survivorship curves that are definitively type I, II, or III. They may be anywhere in between. These three, though, represent the extremes and help us make predictions about reproductive rates and parental investment without extensive observations of individual behavior. For example, humans in less industrialized countries tend to have higher mortality rates in all age intervals, particularly in the earliest intervals when compared to individuals in industrialized countries. Looking at the population of the United States in 1900 (**Figure 2.7b**), you can see that mortality was much higher in the earliest intervals and throughout, the population seemed to exhibit a type II survivorship curve, similar to what might be seen in less industrialized countries or amongst the poorest populations.



Test your knowledge...

Survivorship curves

If a population demonstrates the pattern of a Type III survivorship curve, then:

- a) A large proportion of the young will survive to adulthood.*
- b) Approximately $\frac{1}{2}$ of the newborns in a cohort will survive to adults.*
- c) There will be high infant and juvenile mortality.*
- d) It is likely that each adult only produces one or two offspring at a time and gives each offspring a lot of parental care.*

2.5 The Human Population

For most of human history, there were fewer than 1 billion people on the planet (**Figure 2.8**). During the early part of human history, the human population was held in check by diseases, famines, and wars that made life short and uncertain for most people. At the start of the **Agricultural Revolution**, 10,000 B.C., there were only 5-10 million people on Earth - which is about the size of the population of New York City today. During this revolution, human societies transitioned from small nomadic hunter-gatherer societies to larger stationary farming societies, leading to the first dramatic increase in the human population. This increase resulted from the increase in food supply that made it possible to feed more people. Also, there was need for human labor to run the farms so there was incentive to have many children. People ate better and lived longer resulting in lower death rates while birth rates remained high. This first dramatic increase in population is estimated to have stabilized at around 100 million people, and for many centuries, population increased very slowly.

By the start of the next revolution – the **Industrial Revolution** - in 1800, there were approximately 1 billion people on Earth (**Figure 2.8**). This revolution was marked with progress in agricultural production, engineering, commerce, information technology, sanitation and health care all of which drove death rates down even further and spurred the next more extreme wave of population growth. Improvements in health care and sanitation spread from developed countries to developing ones like India and China, enabling people in all countries around the world to live longer than ever before. It, therefore, took all of human history for population to reach 1 billion people in 1804, only about 150 years to reach 3 billion in 1960, and only 12 years to increase from 5 billion in 1987 to 6 billion in 1999 and again another 12 years to increase to 7 billion in 2011, and only 11 more years to increase to 8 billion in 2022. This clearly demonstrates the capacity of the human population to exhibit exponential growth (**Section 2.2**).

What is the current human population? The reality is that the human population continues to grow every second. So rather than answer this question with an absolute value that quickly becomes outdated, a better option is to provide a population clock that uses an algorithm to keep track of human population growth. These clocks even let you see what the population was at a previous date and project what the population will be at a future date. Two such clocks include one by the US Census Bureau <https://www.census.gov/> and another by an international team of developers, researchers, and volunteers <https://www.worldometers.info/world-population/>. You will notice some difference in population size estimated by the two population clocks but overall, they are within reasonable amounts of one another. A more important question to ask is, how much more will this population growth continue? It is estimated that the current consumption levels combined with the size of the population are way beyond the Earth's carrying capacity. Humans are unique in their ability to alter their

environment with the conscious purpose of increasing this carrying capacity. This ability is a major factor responsible for human population growth and a way of overcoming density- dependent growth regulation. Much of this ability is related to human intelligence, society, and communication.

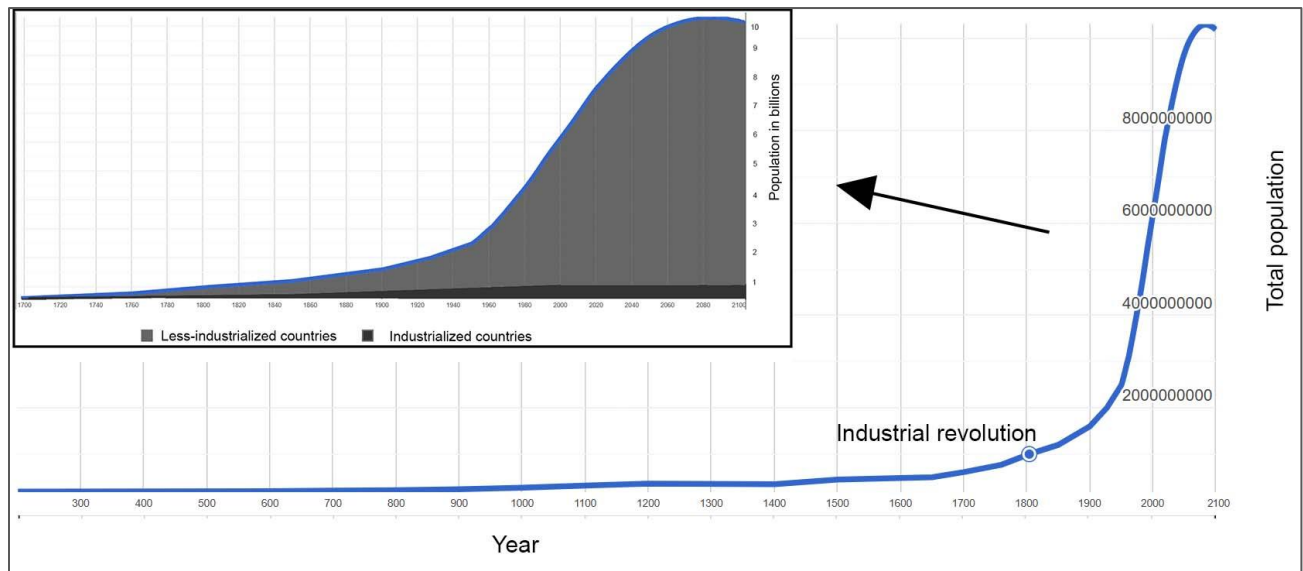


Figure 2.8: Shows the increase in human population size starting from 200 CE and predicted to 2100. The graph shows that for most of human history, human population size was low and stable. The inset image shows population growth in the modern era – outer line is the total world population while shaded regions represent population in industrialized countries (bottom) and less-industrialized/developing countries (top). The greatest amount of human population growth will be in less-industrialized countries. Data used to make the graphs were obtained from the United Nations Population Division; future projections are the UN’s medium variant.

Dire predictions have been made about the growing world’s population leading to a major crisis called the “population explosion.” Thomas Malthus (1766-1834) collected evidence showing that populations tended to increase at an exponential rate while food production remained stable or increased slowly. He predicted that human populations would eventually outstrip their food supply leading to starvation, crimes and misery. **Karl Marx** (1818-1883) presented a different view in which poverty, resource depletion, pollution and other social ills were the cause of population growth and argued that stopping this growth required the elimination of these social ills. These theories about human population growth were developed prior to and did not account for current scientific and technological advances. Food supplies actually increased faster than population growth since Malthus’ time. Progress in agricultural productivity, engineering, information technology, commerce, medicine, sanitation and other achievements of modern life have made it possible to support thousands of times as many people per unit area as was possible 10,000 years ago.

Although humans have increased the carrying capacity of their environment, the technologies used to achieve this transformation have caused unprecedented changes to the environment, altering ecosystems to the point where some may be in danger of collapse. The depletion of the ozone layer, erosion due to acid rain, and damage from global climate change are caused by human activities. The ultimate effect of these changes on our carrying capacity is unknown. As some point out, it is likely that the negative effects of increasing carrying capacity will outweigh the positive ones—the world’s carrying capacity for human beings might actually decrease.



Test your knowledge...

Human exponential growth

*Do you think our current worldwide human population growth is sustainable?
Why or why not?*

2.6 Demography

Demography applies the principles of population ecology to the human population. Demographers study how human populations grow, shrink, and change in terms of age and gender compositions using vital statistics about people such as births, deaths, population size, and where people live. Demographers also compare populations in different countries or regions.

Currently, there are two disparate demographic worlds. On one end is an old, rich, and relatively stable world often referred to as “**industrialized**” or “*developed*” world, and includes many European nations, United States, Canada, Japan, and Australia among others. On the other end is young, poor, and rapidly growing world often referred to as “**less-industrialized**”, “*less-developed*” or “*developing*” and is made up of most people in Asia, Africa, and Latin America. In between these two extremes are countries such as China, India, Brazil, Mexico, South Africa, Russia, and many others that have not quite attained the developed status but have clearly outpaced the so called developing countries. These nations are sometimes referred to as “*newly industrialized*” or “**emerging market economies**”.

2.6.1 Age structure diagrams

One of the tools that demographers use to understand and predict future trends in populations is the **age structure diagram**. This diagram shows the distribution by ages of females and males within a certain population in graphic form. **Figure 2.9** shows an age structure diagram for the United States' population. In this diagram, the ages are arranged so that age ranges are grouped together, for example: 0 – 4 years, 5 – 9 years, and so on. The population of each group is represented as a bar extending from a central vertical line, with the length of each bar dependent upon the total population for that particular group. The centerline separates the females from the males. A closer look at **Figure 2.9** shows slightly more boys in the younger age groups than girls; however, the ratio tends to reverse in the upper age groups, when females tend to outnumber males. Many countries have a female majority as a result of the longer life expectancy for females. Age classes between 0 and 15 years are referred to as *pre-reproductive*, between 15 and 45 years are the *reproductive* age classes and above 45 years are the *post-reproductive* age classes.

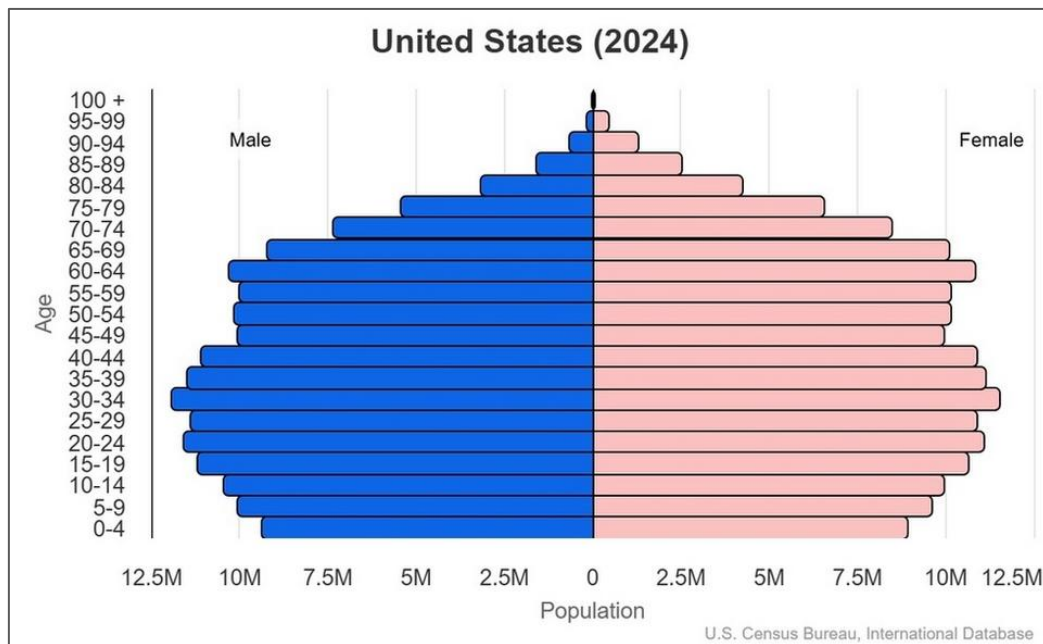


Figure 2.9: Age Structure diagram for the U.S. in 2024. *Source* – Wikimedia – CIA World Factbook. [https://commons.wikimedia.org/wiki/File:United_States_Population_Pyramid_\(2024\).png](https://commons.wikimedia.org/wiki/File:United_States_Population_Pyramid_(2024).png)

An age-structure diagram provides a snapshot of the current population and can represent information about the past and give potential clues about future problems. In **Figure 2.9**, for example, notice the slight bulge among ages 50-54 and 55-59 that represents the so-called “baby boomers”. These are individuals who were born during the baby boom that followed the end of the world war when couples were reunited and

new families started. Also notice the slight bulge among the 20-24 and 25-29 age groups; what do you suppose is the explanation for this bulge?

When interpreting age-structure diagrams, it is important to compare the width of the base to the rest of the population. A country with a stable population, such as the United States (**Figure 2.9**) has nearly the same number of individuals in each age group. Individuals who are born replace those who die so the population remains fairly stable. If the base is very wide compared to the upper parts of the diagram (**Figure 2.10 a**), then this indicates a lot of young people in the population compared to older generations i.e. a high birth rate and a rapidly growing population. An aging population is one with a base that is smaller than the upper parts of the diagram (**Figure 2.10 b**), which implies that more of the population is found in older, post-reproductive age classes than in younger ones. This population is shrinking due to low birth rates and the bulge in the middle represents the age classes for the last high birth rate generation.

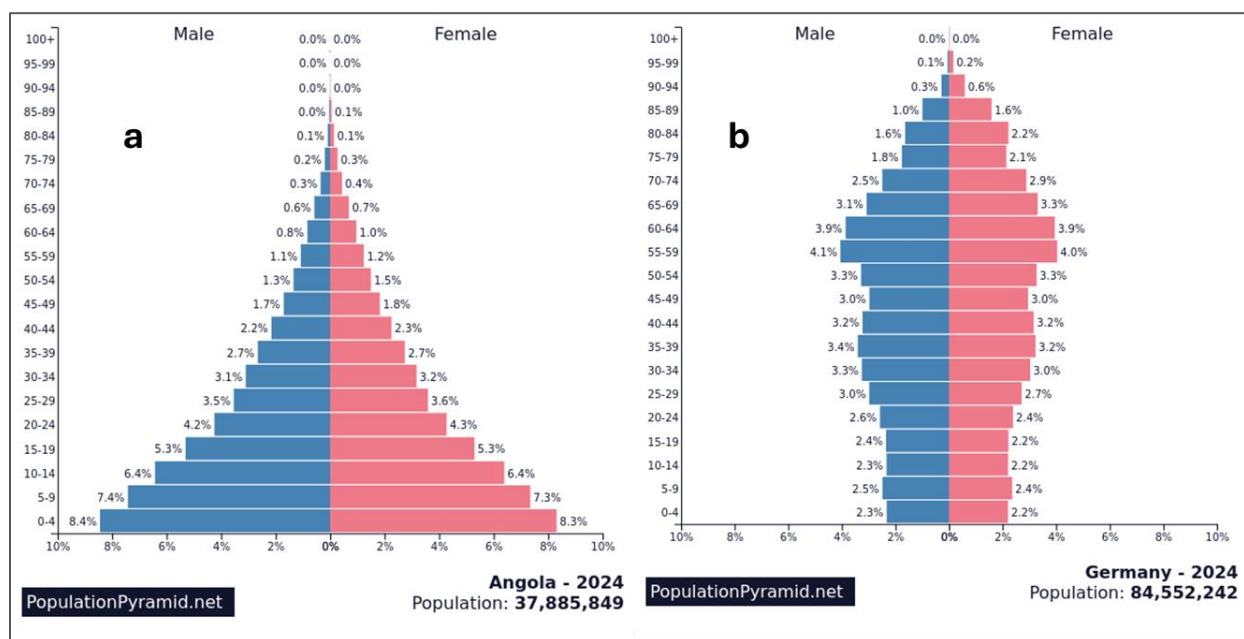


Figure 2.10: Age Structure diagram for Angola (a rapidly growing population) and Germany (a declining population) in 2024. *Source:* PopulationPyramid.net.

Countries with rapidly growing and shrinking populations can have a problem with their **dependency ratio**, the number of nonworking individuals compared to working individuals in a population. In rapidly growing populations, each working person supports a high number of children. In shrinking populations, a small number of working persons have to support a larger number of retired persons with possible dire consequences to the social security system.



Test your knowledge...

Population pyramids

List three things other than population growth that you can discern from a population pyramid.

2.6.2 The Demographic Transition Model

The **demographic transition model** shows the changes in the patterns of birth rates and death rates that typically occur as a country moves through the process of industrialization or development. The demographic transition model was built based on patterns observed in European countries as they were going through industrialization. According to this model, as a country's economy changes from preindustrial to postindustrial, low birth and death rates replace high birth and death rates. This model can be applied to other countries, but not all countries or regions fit the model exactly. And the pace or rate at which a country moves through the demographic transition varies among countries.

In the demographic transition model (**Figure 2.11**), **Stage I** is the *preindustrial stage* in which both birth rates and death rates are high. The high death rates are because of disease and potential food scarcity. A country in Stage I of the demographic transition model does not have good health care; there may not be any hospitals or doctors. Children are not vaccinated against common diseases and many die at a young age. Infant and childhood **mortality rates** (death rates) are very high. A society in Stage I is likely based upon agriculture and most people grow their own food. Therefore, droughts or floods can lead to widespread food shortages and death from famine. All of these factors contribute to the high death rate in Stage I. Partly to compensate for the high death rates, birth rates are also high. High birth rates mean that families are large and each couple, on average, has many children. When death rates are high, having many children means that at least one or two will live to adulthood. In Stage 1, children are an important part of the family workforce and are expected to help growing food and taking care of the family. As you are examining the stages of the demographic transition model, remember that: **Population Growth Rate = Birth Rate – Death Rate**. In Stage I, birth rates are high, but death rates are high as well. Therefore, population growth rate is low or close to zero (**Figure 2.11**). For most of human history, all countries were in Stage I but today, no country is classified in Stage I of this model.

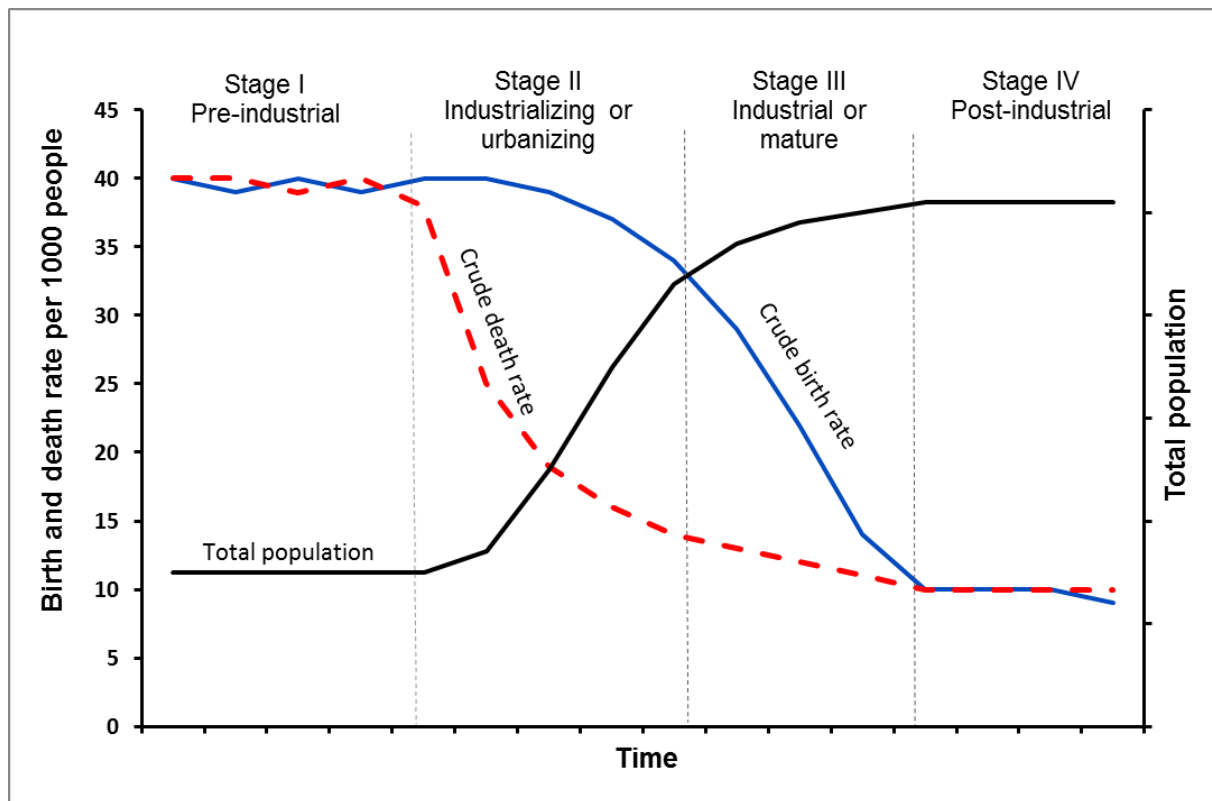


Figure 2.11: Demographic transition model showing high birth and death rates in Stage I transitioning to low birth and death rates in Stage IV. During this time, population starts off as stable but low in Stage I and transitions to stable but high in Stage IV.

As a country develops, medical advances such as access to antibiotics and vaccines are made. Sanitation improvements such as proper waste and sewage disposal, and water treatment for clean drinking water also progress. Food production also increases. Together these changes lead to falling death rates, which mark the beginning of **Stage II** – the *industrializing/urbanizing stage*. Death rates continue to fall throughout Stage II as conditions improve. This means that people are living longer and childhood mortality drops. However, birth rates are still high in Stage II. There is a time lag between the improving conditions and any subsequent changes in family size, so women are still having many children and now more of these children are living into adulthood. In Stage II, the birth rate is higher than the death rate, so population growth rate is high. This means that population size increases greatly during Stage II of the demographic transition model (**Figure 2.11**).

A falling birth rate marks the beginning of **Stage III** – the *mature/industrial stage* – in the demographic transition model. As a country continues to industrialize, many women join the workforce. Additionally, raising children becomes more expensive and children no longer work on the family farm or make large economic contributions to the

family. Individuals may have access to birth control and choose to have fewer children. This leads to a drop in birth rates and smaller family sizes. Death rates also continue to drop during Stage III as medicine, sanitation and food security continue to improve. Even though both birth rates and death rates are falling throughout Stage III, birth rates are still higher than death rates. This means that population growth rate is high and that population size continues to increase in Stage III of the demographic transition model.

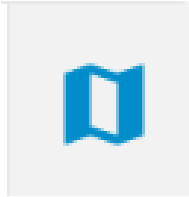
Birth rate and death rates drop to low, stable, approximately equal levels in Stage IV – the *post- industrial stage*. Death rates are low because of medical advances, good sanitation, clean drinking water and food security. Most people are therefore dying of old age. Birth rates are low because of access to birth control and many women in the workforce delay marriage and having their first child until they have established their careers. Childhood mortality is low, life expectancy is high, and family size is approximately two children per couple. With low birth rates and low death rates, population growth rate is approximately zero in Stage IV.

2.6.3 Life expectancy

Life expectancy is the average number of years that a person in a particular population is expected to live (average age at death). Life expectancy at birth is the number of years a newborn infant would live if mortality rates at the time of its birth did not change. For example, the life expectancy at birth for someone born in 2024 in Japan is 85.2 years while the life expectancy at birth for someone born in the United States in 2024 is 80.9 years (source: <https://www.cia.gov>). As a country moves through the demographic transition model, life expectancy increases. Overall, life expectancy has increased for most countries and regions over the past 100 years. The main cause of population growth has not been increased fertility but rather declining death rates due primarily to better food and better sanitation. For most of human history, it is believed that average life expectancy in most societies was about 30 years. In 1900, the world average life expectancy was only about 30 years. By 2006, the average age was 64.3 years, attributed to better nutrition, sanitation, and medical care.

Global life expectancy increased from 66.8 years in 2000 to 73.1 years in 2019. However, the COVID-19 pandemic reversed this in just two years, setting global life expectancy back to 72.5 years, which is the 2016 level. (source: <https://www.who.int>)

While overall life expectancy has increased worldwide, there is still a significant variation in life expectancy in different regions of the world with a significant discrepancy between rich and poor countries. For example, the life expectancy of an individual born in Lesotho in 2024 is 60.2 years, more than 30 years less than an individual born the same year in Japan.



Use this World Health Organization interactive map to compare life expectancy among different countries:
[https://www.who.int/data/gho/data/indicators/indicator-details/GHO/life-expectancy-at-birth-\(years\)](https://www.who.int/data/gho/data/indicators/indicator-details/GHO/life-expectancy-at-birth-(years)). Click on the symbol on the left side of the screen for the map.



Test your knowledge...

Using the World Health Organization interactive map, answer these questions:

1. *What other countries have a life expectancy at birth similar to the United States?*
2. *List two countries that have a higher life expectancy and two countries that have a lower life expectancy than the United States.*

2.6.4 Fertility

Fertility describes the actual production of offspring. One demographic statistic of fertility is the **crude birth rate**, which is the number of births in a year per thousand people. It is referred to as “crude” because it is not adjusted for important population characteristics such as the number of women of reproductive age. Another statistic is **total fertility rate** (TFR), which is the number of children born to each woman in a population, over the woman’s lifespan. The TFR differs considerably between regions as is clearly demonstrated by **Figure 2.12**. However, the forces that determine a region’s or country’s TFR are generally the same, including healthcare, education, economic conditions (**Figure 2.13**), culture, and religion. These factors all work together to determine a country’s **desired fertility** (the number of children the average couple says they want to have), which in turn influences the TFR. Factors that increase people’s desire to have children are known as **pronatalist pressures**.

Countries in the pre-industrial and industrializing stages of the demographic transition (Stage I and II respectively) have higher TFR but this decreases considerably as countries move to the industrialized and post-industrial stages. Prior to industrialization, high infant mortality rate (the number of infants who die in their first year of life per 1000 births) leads couples to have more children in order to increase the odds that at least some will survive to adulthood. Other factors that result in high TFR include: poverty; need for children to work on farms, tend to household chores and

care for parents as they age; and lack of access to contraception for women due to inability to afford birth control, cultural taboos against its use, or pressures from patriarchal societies that view children as a sign of male fertility. Poverty is strongly correlated with high TFR, as poorer societies tend to show higher population growth rates than do wealthier societies.

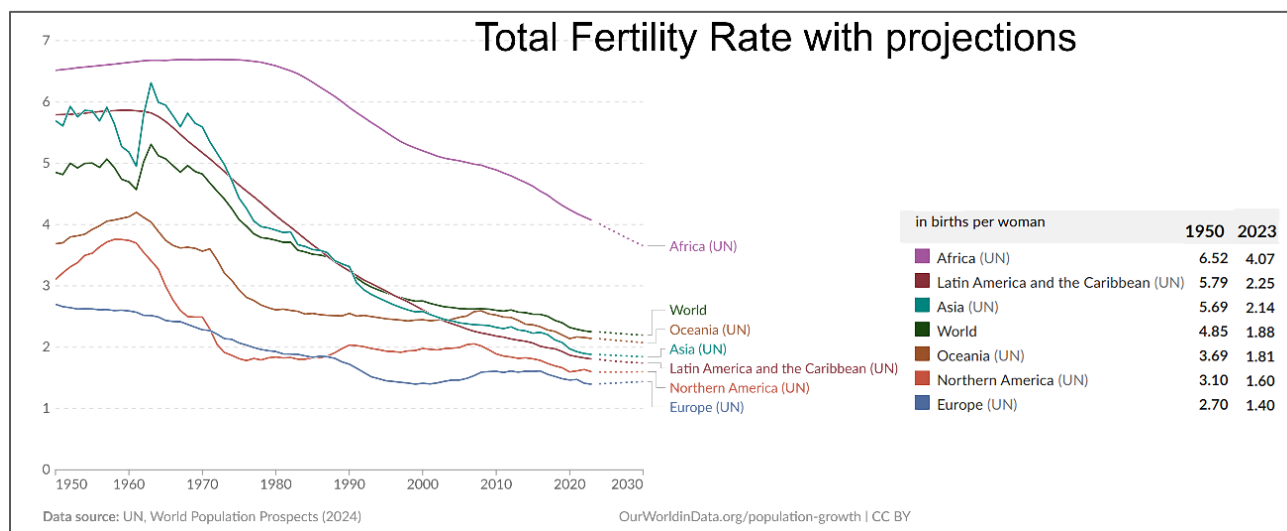


Figure 2.12: Total fertility of different regions of the world since 1950 with projections until 2030. Graph and date are from UN, World Population Prospects (2024).
<https://ourworldindata.org/grapher/fertility-rate-with-projections>

However, this relationship operates in both directions because rapid population growth tends to worsen poverty. As countries advance through the demographic transition, improved medical care reduces **infant mortality rates** making it less necessary to have many children. Urbanization removes the need for children to contribute to farm labor and children are required to go to school, imposing economic costs on their families. Many governments also provide some form of social security, which reduces the need for parents to have many children to support them in their old age. With greater educational opportunities and changing roles in society, women tend to shift into the labor force, putting less emphasis on child rearing.

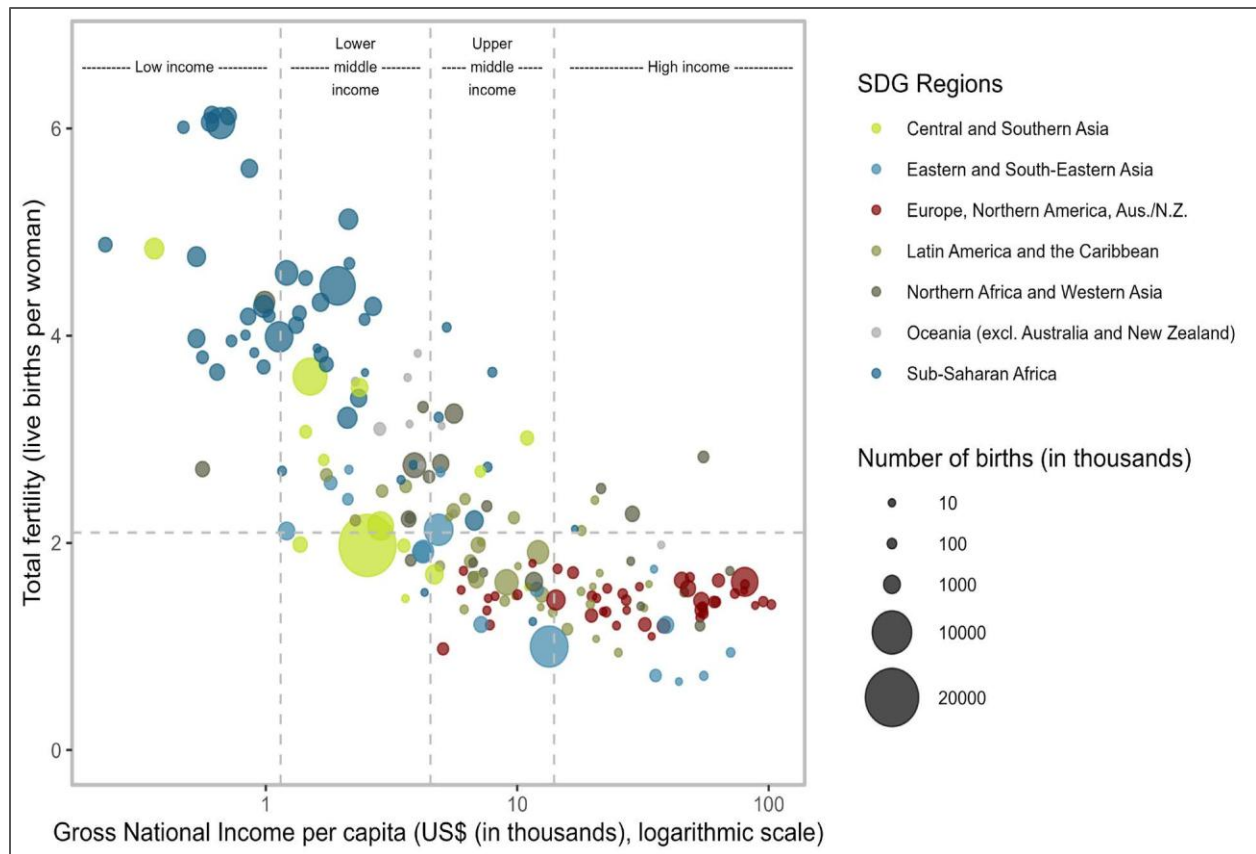


Figure 2.13: Total fertility by gross national income (GNI) per capita, countries and areas. The size of the bubbles is determined by the number of births in 2024. The dashed gray horizontal line indicates the level of replacement fertility. The dashed gray vertical lines indicate the cut-off data points of GNI per capita used in the World Bank country classifications by income level for 2024–2025. More developed regions include Europe, Northern America (US and Canada), Australia, New Zealand and Japan. Less developed regions comprise all regions of Africa, Asia (except Japan), Latin America and the Caribbean plus Melanesia, Micronesia and Polynesia. Oceania includes Australia, New Zealand, Melanesia, Micronesia and Polynesia. Graph and data are from United Nations (2024a), World Bank (2024). https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undesa_pd_2025_wfr_2024_final.pdf

Overall, fertility rates have decreased for most countries and regions over the past 50 years (**Figure 2.12**). However, there is still a significant amount of variation among different regions of the world, with Africa still showing high TFR. The goal is to achieve **zero population growth**, when the population size is neither increasing nor decreasing. This occurs when the number of people born (birth rate) equals the number of people dying (death rate). Zero population growth is realized when the population reaches the **replacement fertility rate**, meaning that every couple only has enough children to replace themselves. The global replacement fertility rate is currently estimated to be **2.1** children per woman rather than 2 because not all children survive and not all couples have children. **Figure 2.14** shows the number of

countries by region that have achieved replacement fertility rate (below 2.1 births per woman) with projections until 2100.

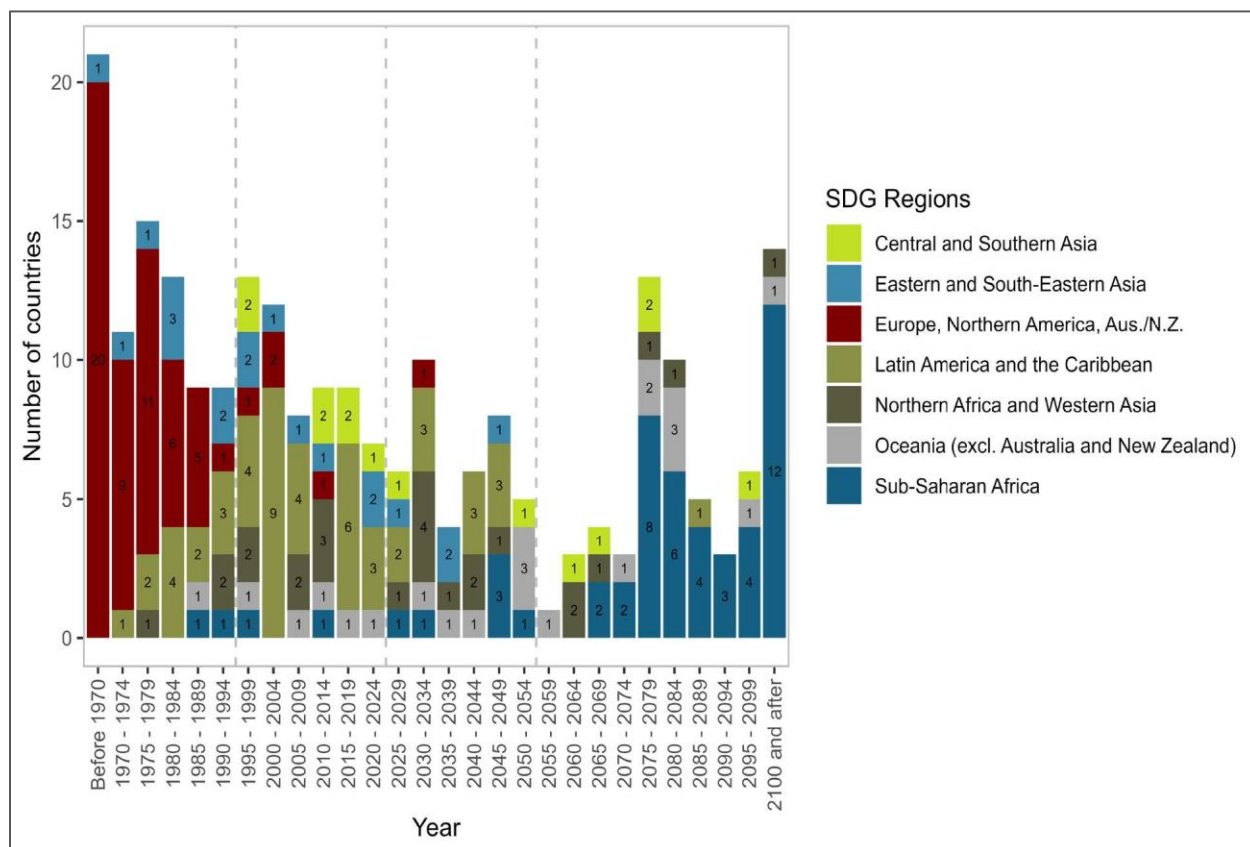


Figure 2.14: Number of countries and areas by period reaching total fertility below 2.1 births per woman, by region, estimates for 1950–2023 and projections for 2024–2100. Graph and data are from [United Nations \(2024a\)](#)



Test your knowledge...

Population growth and demographic transition

*Provide an argument for and against the following statement: “**Population growth in less industrialized countries is a bigger concern than population growth in industrialized countries.**”*

End of Chapter Review

1. A country experiencing zero population growth is most likely
 - a. In stage 1 of the demographic transition
 - b. In stage 4 of the demographic transition
 - c. Economically underdeveloped
 - d. Experiencing higher death rates than birth rates
2. Which of the following is a time period with the most rapid human population growth rate?
 - a. 10, 000 B.C. to the year 1000
 - b. 1800 – 1900
 - c. 1700 - 1800
 - d. 1950 - present
3. Which of the following is found in Stage I of the demographic transition model?
 - a. Poor countries in Africa
 - b. Poor countries in South America
 - c. Poor countries in Asia
 - d. No country is classified in Stage I
4. Growth in natural populations is limited by availability of resources but the human population has continued to grow beyond the Earth's carrying capacity. Explain the reasons why this is.
5. Consider two populations each experiencing exponential growth and both have the same population size. At the end of one year, Population A has a higher population growth rate than population B. Explain why.
6. Two populations start with same population size and have the same per capita rate of increase. At the end of a year, population A has a much larger population growth rate than population B. What is the most likely explanation for the difference.
7. Total fertility rate (TFR) is influenced by various social, economic, and cultural factors. Explain how each of these factors will affect TFR and ultimately population growth: poverty, infant mortality rate, access to birth control, level of urbanization, education of women, life expectancy.
8. If a population is experiencing exponential growth, what happens to **N**, **r** and **G** over time (increase, decrease or stay the same)?
9. At the beginning of the year, there are 7650 individuals in a population of beavers whose *per capita rate of increase* for the year is 0.18. What is its *population growth rate* at the end of the year?
10. A zebrafish population of 1000 individuals lives in an ecosystem that can support a maximum of 2000 zebrafish. The per capita rate of increase for the population is 0.01 for the year. What is the population growth rate?

11. A chipmunk population is experiencing exponential growth with a population growth rate of 265 individuals/year, and a per capita rate of increase of 0.15. How many chipmunks are currently in this population?
12. Scientists discovered a new species of frog and were able to estimate its population at 755 individuals. At the end of the year, there were 860 frogs. Assuming the population is undergoing exponential growth, what is the *per capita rate of increase*?
13. A wildlife ranch currently has a population of polar bears whose death rate is 0.05 and birth rate is 0.12 per year. This particular ranch is isolated from other suitable habitats so there's no immigration into or emigration from this population. This population is experiencing logistic growth and currently has 550 bears. If the population growth rate for the year was 36 bears, what is the carrying capacity of the preserve?
14. Explain why a country with the highest consumption may not have the largest population.

Resources

- United Nations Department of Economic and Social Affairs. 2024. World Fertility:
https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undesa_pd_2025_wfr_2024_final.pdf
- United States Census. U.S. and World Population Clock:
<https://www.census.gov/popclock/>
- World Health Organization. 2025. Global Health Observatory: Life expectancy at birth:
[https://www.who.int/data/gho/data/indicators/indicator-details/GHO/life-expectancy-at-birth-\(years\)](https://www.who.int/data/gho/data/indicators/indicator-details/GHO/life-expectancy-at-birth-(years))
- World-o-meter. Current World Population:
<https://www.worldometers.info/world-population/>
- Parts of this chapter have been modified from the OpenStax textbooks: Biology. OpenStax CNX. May 13, 2015 <http://cnx.org/contents/185cbf87-c72e-48f5-b51e-f14f21b5eabd@9.85>

Terms

Age structure	Life table
Age structure diagram	Logistic growth
Agricultural Revolution	Model
Carrying capacity (K)	per capita rate of increase (r)
Charles Darwin	Population
Crude birth rate	Population density
Demographic Transition Model	Population ecology
Demography	Population growth rate (G)
Density-dependent factors	Population size (N)
Density-independent factors	Pronatalist pressures
Dependency ratio	Replacement fertility rate
Desired fertility	Sex ratio
Dispersion	Stage I population
Emerging market economies	Stage II population
Emigration	Stage III population
Exponential growth	Stage IV population
Fertility	Survivorship
Immigration	Survivorship curve
Industrial Revolution	Thomas Malthus
Industrialized nation	Total fertility rate
Infant mortality rate	Type I survivorship curve
Karl Marx	Type II survivorship curve
Less-industrialized nation	Type III survivorship curve
Life expectancy	Zero population growth