CHAPTER 4

The Human Population and the Environment

In 2009, people around the world wore masks to protect themselves against swine flu.

LEARNING OBJECTIVES

The human population has been growing rapidly for centuries. What is happening and, most important, what *will* happen to all of us and our planet if this continues? After reading this chapter, you should understand that . . .

- Ultimately, there can be no long-term solutions to environmental problems unless the human population stops increasing;
- Two major questions about the human population are (1) what controls its rate of growth and (2) how many people Earth can sustain;
- Modern medical practices and improvements in sanitation, control of disease-spreading organisms, and supplies of human necessities have lowered death rates and accelerated the net rate of human population growth;
- Although the death rate has declined, so more people live longer, the rapid increase in the human population has occurred with little or no change in the maximum lifetime of an individual, which is still less than 120 years;
- In general, countries with a high standard of living have moved more quickly to a lower birth rate than have countries with a low standard of living;
- Although we cannot predict with absolute certainty what the future human carrying capacity of Earth will be, an understanding of human population dynamics can help us make useful forecasts;
- The principles of population dynamics discussed in this chapter apply to populations of all species and will be useful throughout this book.

CASE STUDY

Pandemics and World Population Growth

On April 14, 2009, the Mexican government reported the first case of a new strain of flu. A genetic combination of flu found in pigs, birds, and people, it was immediately called "swine flu" but formally referred to as flu strain A (H1N1). Because this was a new strain, little natural resistance to it could be expected, and it thus might cause a worldwide disease outbreak—the kind known as a **pandemic**. Indeed, this flu traveled rapidly. By May 1, it had spread to 11 nations.[1]

Nations responded quickly. The government of Hong Kong quarantined a major hotel where one guest from Mexico was diagnosed with the flu. The Mexican government provided open access to information and declared a special "holiday" in Mexico City to prevent the spread of the disease there.

Even so, by mid-May 2009 the disease had spread to 33 nations, causing almost 6,500 cases but few deaths (Figure 4.1). Although it had become widespread rapidly, concerns about swine flu had greatly diminished because it appeared to be a rather mild form of the disease and quick responses seemed to have mostly contained it. Concerns remained, however, that it might spread to the Southern Hemisphere and, during its winter, mutate to a more virulent form, then return to the Northern Hemisphere in the winter of 2009 as a greater threat.

Because this strain of flu did not become a full-blown pandemic and seemed relatively mild, it is easy to believe that nations overreacted. But the failure of this flu to spread more widely appears due in large part to the rapid and widespread response. And the history of recent new diseases—particularly West Nile virus and SARS—supported such a response.

Before 1999, West Nile virus occurred in Africa, West Asia, and the Middle East, but not in the New World. Related to encephalitis, West Nile virus is spread by mosquitoes, which bite infected birds, ingest the virus, and then bite people. It reached the Western Hemisphere through infected birds and has now been found in more than 25 species of birds native to the United States, including crows, the bald eagle, and the black-capped chickadee—a common visitor to bird feeders in the U.S. Northeast. Fortunately, in human beings this disease has lasted only a few days and has rarely caused severe symptoms.[2] By 2007, more than 3,600 people in the United States had contracted this disease, most in California and Colorado, with 124 fatalities.[3] But the speed with which it spread led to concerns about other possible new pandemics.

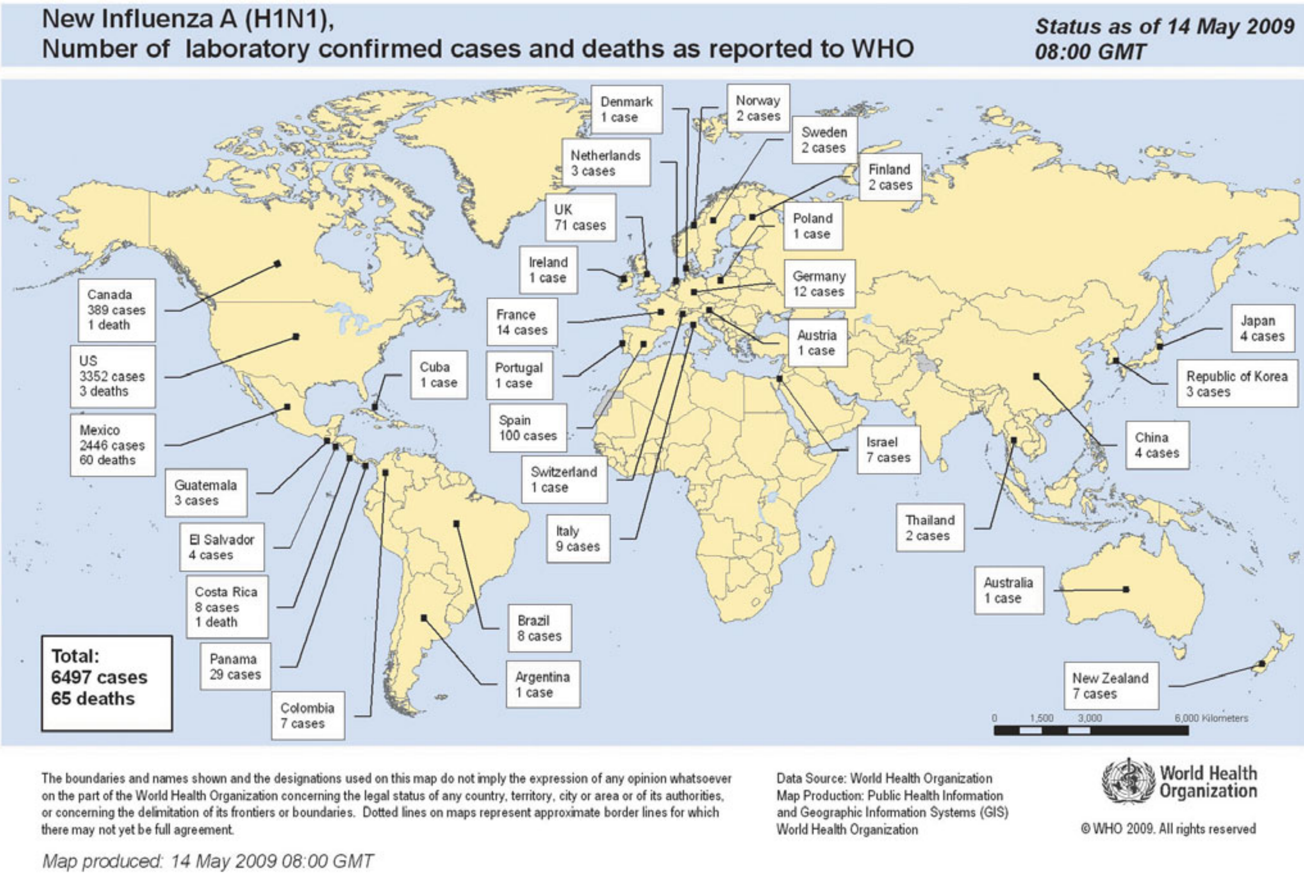
Four years earlier, in February 2003, the sudden occurrence of a new disease, severe acute respiratory syndrome (SARS), had demonstrated that modern transportation and the world's huge human population could lead to the rapid spread of epidemic diseases. Jet airliners daily carry vast numbers of people and goods around the world. The disease began in China, perhaps spread from some wild animal to human beings. China had become much more open to foreign travelers, with more than 90 million visitors in a recent year.[4] By late spring 2003, SARS had spread to two dozen countries; more than 8,000 people were affected and 774 died. Quick action, led by the World Health Organization (WHO), contained the disease.[5]

And behind all of this is the knowledge of the 1918 world flu virus, which is estimated to have killed as many as 50 million people in one year, probably more than any other single epidemic in human history. It spread around the world in the autumn, striking otherwise healthy young adults in particular. Many died within hours! By the spring of 1919, the virus had virtually disappeared.[6]

Although outbreaks of the well-known traditional epidemic diseases have declined greatly during the past century in industrialized nations, there is now concern that the incidence of pandemics may increase due to several factors. One is that as the human population grows, people live in new habitats, where previously unknown diseases occur. Another is that strains of disease organisms have developed resistance to antibiotics and other modern methods of control.

A broader view of why diseases are likely to increase comes from an ecological and evolutionary perspective (which will be explained in later chapters). Stated simply, the more than 6.6 billion people on Earth constitute a great resource and opportunity for other species; it is naive to think that other species will not take advantage of this huge and easily accessible host. From this perspective, the future promises more diseases rather than fewer. This is a new perspective. In the mid-20th century it was easy to believe that modern medicine would eventually cure all diseases and that most people would live the maximum human life span. It is generally believed, and often forecast, that the human population will simply continue increasing, without any decline. But with increased crowding and its many effects on the environment, there is also concern that the opposite might happen, that our species might suffer a large, if temporary, dieback. This leads us to consider how populations change over time and space, especially our own populations, and this is the subject of the present chapter.

FIGURE 4.1 **(a)** A couple try to take appropriate measures to protect against swine flu. **(b)** Map of the flu's distribution by mid-May 2009.
(*Source*: **(b)** World Health Organization).



4.1 Basic Concepts of Population Dynamics

One of the most important properties of living things is that their abundances change over time and space. This is as true for our own species as it is for all others, including those that directly or indirectly affect our lives—for example, by providing our food, or materials for our shelter, or causing diseases and other problems—and those that we just like having around us or knowing that they exist.

In this chapter we focus on the human population because it is so important to all environmental problems, but the concepts we discuss here are useful for the populations of all species, and we will use these concepts throughout this book. You should also familiarize yourself with the following definitions and ideas:

- **Population dynamics** is the general study of population changes.
- A **population** is a group of individuals of the same species living in the same area or interbreeding and sharing genetic information.

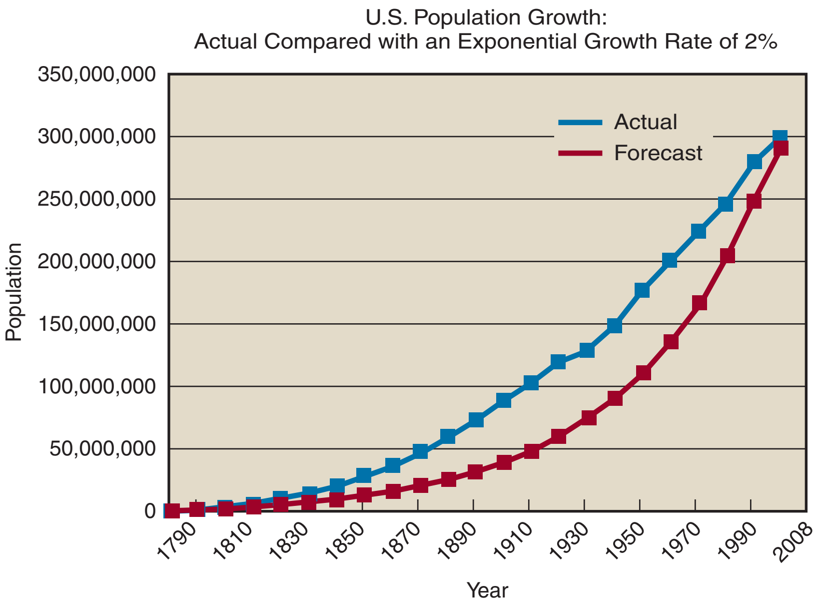


FIGURE 4.2 U.S. population, 1790 to 2008. The actual population growth is shown compared to an exponential curve with an annual growth rate of 2%. (*Source*: Data from U.S. Census Bureau, *US Historical Population Information*.)

- A **species** is all individuals that are capable of interbreeding, and so a species is composed of one or more populations.
- **Demography** is the statistical study of human populations, and people who study the human population include demographers.
- Five key properties of any population are **abundance**, which is the size of a population; **birth rates**; **death rates**; **growth rates**; and **age structure.** How rapidly a population's abundance changes over time depends on its growth rate, which is the difference between the birth rate and the death rate.
- The three rates—birth, death, and growth—are usually expressed as a percentage of a population per unit of time. For people, the unit of time is typically a year or greater. Sometimes these rates are expressed as actual numbers within a population during a specified time. (See Useful Human-Population Terms in Section 4.1.)

Let us begin with the population of the United States, which has grown rapidly since European settlement (Figure 4.2).

The Human Population as an Exponential Growth Curve

It is common to say that human populations, like that of the United States, grow at an **exponential rate**, which means that the annual growth rate is a constant percentage of the population (see Chapter 3). But Figure 4.2 shows that for much of the nation's history the population has grown at a rate that exceeds an exponential. The annual growth rate has changed over time, increasing in the early years, in part because of large immigrations to North America, and decreasing later. An exponential curve growing at 2% per year lags the actual increase in the U.S. population for most of the nation's history but catches up with it today. That is because the growth rate has slowed considerably. It is now 0.6%; in contrast, between 1790 and 1860, the year the Civil War began, the population increased more than 30% per year! (This is a rate that for a human population can be sustained only by immigration.)

Like that of the U.S. population, the world's human population growth is typically also shown as an exponential (Figure 4.3), although we know very little about the variation in the number of people during the early history of our species.

We can divide the history of our species' population into four phases (see A Closer Look 4.1 for more about this history). In Stage 1, the early period of hunters and gatherers, the world's total human population was probably less than a few million. Stage 2 began with the rise of agriculture, which allowed a much greater density of people and the first major increase in the human population. Stage 3, the Industrial Revolution in the late 18th and early 19th centuries, saw improvements in health care and the food supply, which led to a rapid increase in the human population. The growth rate of the world's human population, like that of the early population of the United States, increased but varied during the first part of the 20th century, peaking in 1965–1970 at 2.1% because of improved health care and food production. Stage 4 began around the late 20th century. In this stage, population growth slowed in wealthy, industrialized nations, and although it has continued to increase rapidly in many poorer, less developed nations, globally the growth rate is declining and is now approximately 1.2%.[8]

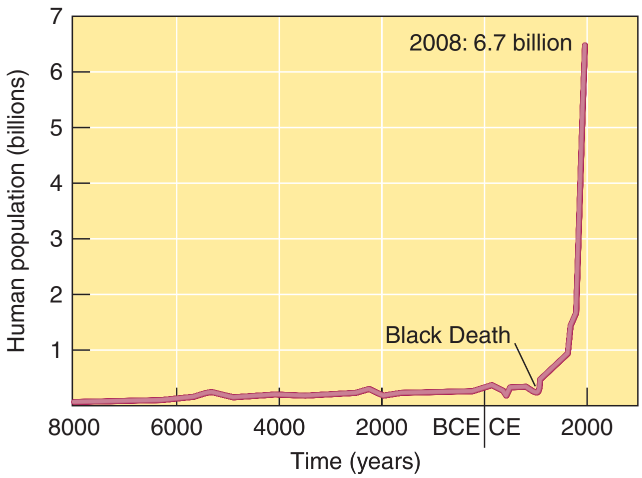


FIGURE 4.3 Human Population Growth. It took thousands of years for the human population to reach 1 billion (in 1800) but only 130 years to reach 2 billion (1930). It only took 130 years to reach 3 billion (1960), 15 years to reach 4 billion (1975), 12 years to reach 5 billion (1987), and 12 years to year 6 billion (1999). (*Source*: Reprinted with permission of John Wiley & Sons, Inc.)

Usually in discussions of population dynamics, birth, death, and growth rates are expressed as percentages (the number per 100 individuals). But because the human population is so huge, percentages are too crude a measure, so it is common to state these rates in terms of the number per 1,000, which is referred to as the crude rate. Thus we have the *crude birth rate*, *crude death rate*, and *crude growth rate*. More specifically, here is a list of terms that are used frequently in discussions of human population change and will be useful to us in this book from time to time.

Table 4.1 USEFUL HUMAN-POPULATION TERMS

Crude birth rate: number of births per 1,000 individuals per year; called "crude" because population age structure is not taken into account.

Crude death rate: number of deaths per 1,000 individuals per year.

Crude growth rate: net number added per 1,000 individuals per year; also equal to the crude birth rate minus crude death rate.

Fertility: pregnancy or the capacity to become pregnant or to have children.

General fertility rate: number of live births expected in a year per 1,000 women aged 15–49, considered the childbearing years.

Total fertility rate (TFR): the average number of children expected to be born to a woman throughout her childbearing years.

Age-specific birth rate: number of births expected per year among a fertility-specific age group of women in a population.The fertility-specific age group is, in theory, all ages of women that could have children. In practice, it is typically assumed to be all women between 15 and 49 years old.

Cause-specific death rate: the number of deaths from one cause per 100,000 total deaths.

Morbidity: a general term meaning the occurrence of disease and illness in a population.

Incidence: with respect to disease, the number of people contracting a disease during a specific time period, usually measured per 100 people.

Prevalence: with respect to a disease, the number of people afflicted at a particular time.

Case fatality rate: the percentage of people who die once they contract a disease.

Rate of natural increase (RNI): the birth rate minus the death rate, implying an annual rate of population growth not including migration.

Doubling time: the number of years it takes for a population to double, assuming a constant rate of natural increase.

Infant mortality rate: the annual number of deaths of infants under age 1 per 1,000 live births.

Life expectancy at birth: the average number of years a newborn infant can expect to live given current mortality rates.

GNP per capita: gross national product (GNP), which includes the value of all domestic and foreign output.

(Source: C. Haub and D. Cornelius, *World Population Data Sheet* [Washington, DC: Population Reference Bureau, 1998].)

A CLOSER LOOK 4.1

A Brief History of Human Population Growth

STAGE 1. Hunters and Gatherers: From the first evolution of humans to the beginning of agriculture.[7]

Population density: About 1 person per 130–260 km^2 in the most habitable areas.

Total human population: As low as one-quarter million, less than the population of modern small cities like Hartford, Connecticut, and certainly fewer than the number of people—commonly a few million—who now live in many of our largest cities.

Average rate of growth: The average annual rate of increase over the entire history of human population is less than 0.00011% per year.

STAGE 2. Early, Preindustrial Agriculture: Beginning sometime between 9000 B.C. and 6000 B.C. and lasting until approximately the 16th century.

Population density: With the domestication of plants and animals and the rise of settled villages, human population density increased greatly, to about 1 or 2 people/km^2 or more, beginning a second period in human population history.

Total human population: About 100 million by A.D. 1 and 500 million by A.D. 1600.

Average rate of growth: Perhaps about 0.03%, which was high enough to increase the human population from 5 million in 10,000 B.C. to about 100 million in A.D. 1. The Roman Empire accounted for about 54 million. From A.D. 1 to A.D. 1000, the population increased to 200–300 million.

STAGE 3. The Machine Age: Beginning in the 16th century.

Some experts say that this period marked the transition from agricultural to literate societies, when better medical care and sanitation were factors in lowering the death rate.

Total human population: About 900 million in 1800, almost doubling in the next century and doubling again (to 3 billion) by 1960.

Average rate of growth: By 1600, about 0.1% per year, with rate increases of about 0.1% every 50 years until 1950. This rapid increase occurred because of the discovery of causes of diseases, invention of vaccines, improvements in sanitation, other advances in medicine and health, and advances in agriculture that led to a great increase in the production of food, shelter, and clothing.

STAGE 4. The Modern Era: Beginning in the mid-20th century.

Total human population: Reaching and exceeding 6.6 billion.

Average rate of growth: The growth rate of the human population reached 2% in the middle of the 20th century and has declined to 1.2%.[8]

How Many People Have Lived on Earth?

Before written history, there were no censuses. The first estimates of population in Western civilization were attempted in the Roman era. During the Middle Ages and the Renaissance, scholars occasionally estimated the number of people. The first modern census was taken in 1655 in the Canadian colonies by the French and the British.[9] The first series of regular censuses by a country began in Sweden in 1750, and the United States has taken a census every decade since 1790. Most countries began counting their populations much later. The first Russian census, for example, was taken in 1870. Even today, many countries do not take censuses or do not do so regularly. The population of China has only recently begun to be known with any accuracy. However, studying modern primitive peoples and applying principles of ecology can give us a rough idea of the total number of people who may have lived on Earth.

Summing all the values, including those since the beginning of written history, about 50 billion people are estimated to have lived on Earth.[10] If so, then, surprisingly, the more than 6.6 billion people alive today represent more than 10% of all of the people who have ever lived.

4.2 Projecting Future Population Growth

With human population growth a central issue, it is important that we develop ways to forecast what will happen to our population in the future. One of the simplest approaches is to calculate the doubling time.

Exponential Growth and Doubling Time

Recall from Chapter 3 and from the preceding list of Useful Human Population Terms that **doubling time**, a concept used frequently in discussing human population growth, is the time required for a population to double in size (see Working It Out 4.1). The standard way to estimate doubling time is to assume that the population is growing exponentially and then divide 70 by the annual growth rate stated as a percentage. (Dividing into 70 is a consequence of the mathematics of exponential growth.)

The doubling time based on exponential growth is very sensitive to the growth rate—it changes quickly as the growth rate changes (Figure 4.4). A few examples demonstrate this sensitivity. With a current population growth of 1.0%, the United States has a doubling time of 70 years. In contrast, the current growth rate of Nicaragua is 2.0%, giving that nation a doubling time of 35 years. Sweden, with an annual rate of about 0.2%, has a doubling time of 350 years. The world's most populous country, China, has a growth rate of 0.6% and a 117-year doubling time.[11]

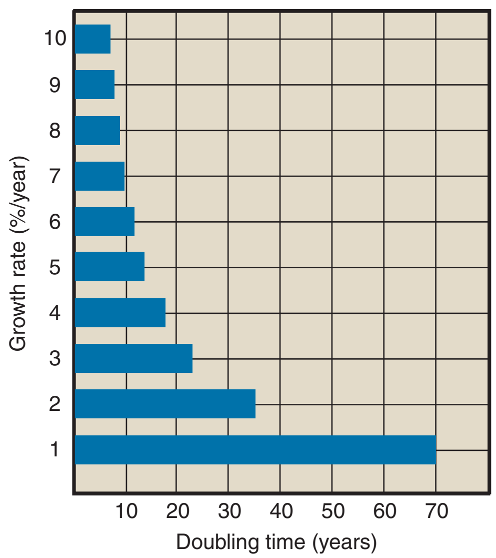


FIGURE 4.4 Doubling time changes rapidly with the population growth rate. Because the world's population is increasing at a rate between 1 and 2%, we expect it to double within the next 35 to 70 years.

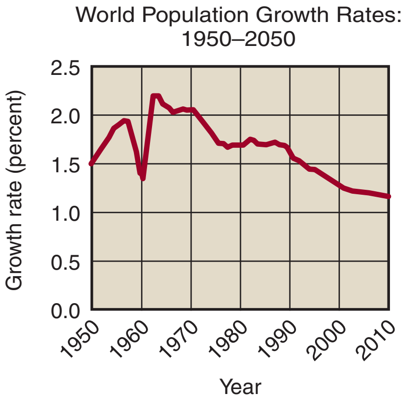


FIGURE 4.5 The annual growth rate of the world's population has been declining since the 1960s.

The world's population growth rate peaked in the 1960s at about 2.2% and is now about 1.1% (Figure 4.5). If the growth rate had continued indefinitely at the 1960s peak, the world population would have doubled in 32 years. At today's rate, it would double in 64 years.

Human Population as a Logistic Growth Curve

An exponentially growing population theoretically increases forever. However, on Earth, which is limited in size, this is not possible, as Thomas Henry Malthus pointed out in the 18th century (see A Closer Look 4.2). Eventually the population would run out of food and space and become increasingly vulnerable to catastrophes, as we are already beginning to observe. Consider, a population of 100 increasing at 5% per year would grow to 1 billion in less than 325 years. If the human population had increased at this rate since the beginning of recorded history, it would now exceed all the known matter in the universe.

If a population cannot increase forever, what changes in the population can we expect over time? One of the first suggestions made about population growth is that it would follow a smooth S-shaped curve known as the **logistic growth curve** (see Chapter 3). This was first suggested in 1838 by a European scientist, P. F. Verhulst, as a theory for the growth of animal populations. It has been applied widely to the growth of many animal populations, including those important in wildlife management, endangered species and those in fisheries (see Chapter 13), as well as the human population.

WORKING IT OUT 4.1 Forecasting Population Change

Populations change in size through births, deaths, immigration (arrivals), and emigration (departures). We can write a formula to represent population change in *terms of actual numbers in a population*:

$$P_2 = P_1 + (B - D) + (I - E)$$

where P_1 is the number of individuals in a population at time 1, P_2 is the number of individuals in that population at some later time 2, B is the number of births in the period from time 1 to time 2, D is the number of deaths from time 1 to time 2, I is the number entering as immigrants, and E is the number leaving as emigrants.

So far we have expressed population change in terms of total numbers in the population. We can also express these as rates, including the birth rate (number born divided by the total number in the population), death rate (number dying divided by the total number in the population), and growth rate (change in the population divided by the total number in the population). (In this section, we will use lowercase letters to represent a rate, uppercase letters to represent total amounts.)

Ignoring for the moment immigration and emigration, how rapidly a population changes depends on the growth rate, g, which is the difference between the birth rate and the death rate (see earlier list of useful terms). For example, in 1999 the crude death rate, d, in the United States was 9, meaning that 9 of every 1,000 people died each year. (The same information expressed as a percentage is a rate of 0.9%.) In 1999 the crude birth rate, b, in the United States was 15.[12] The crude growth rate is the net change—the birth rate minus the death rate. Thus the crude growth rate, g, in the United States in 1999 was 6. For every 1,000 people at the beginning of 1999, there were 1,006 at the end of the year.

Continuing for the moment to ignore immigration and emigration, we can state that how rapidly a population grows depends on the difference between the birth rate and the death rate. The growth rate of a population is then

$$g = (B - D)/N \quad \text{or} \quad g = G/N$$

Note that in all these cases, the units are numbers per unit of time.

It is important to be consistent in using the population at the beginning, middle, or end of the period. Usually, the number at the beginning or the middle is used. Consider an example: There were 19,700,000 people in Australia in mid-2002, and 394,000 births from 2002 to 2003. The birth rate, b, calculated against the mid-2002 population was 394,000/19,700,000, or 2%. During the same period, there were 137,900 deaths; the death rate, d, was 137,900/19,700,000, or 0.7%. The growth rate, g, was (394,000 – 137,900)/19,700,000, or 1.3%.[13]

Recall from Chapter 3 that doubling time—the time it takes a population to reach twice its present size—can be estimated by the formula

$$T = 70/\text{annual growth rate}$$

where T is the doubling time and the annual growth rate is expressed as a percentage. For example, a population growing 2% per year would double in approximately 35 years.

A logistic population would increase exponentially only temporarily. After that, the rate of growth would gradually decline (i.e., the population would increase more slowly) until an upper population limit, called the **logistic carrying capacity**, was reached. Once that had been reached, the population would remain at that number.

Although the logistic growth curve is an improvement over the exponential, it too involves assumptions that are unrealistic for humans and other mammals. Both the exponential and logistic assume a constant environment and a homogeneous population—one in which all individuals are identical in their effects on each other. In addition to these two assumptions, the logistic assumes a constant carrying capacity, which is also unrealistic in most cases, as we will discuss later. There is, in short, little evidence that human populations—or any animal populations, for that matter—actually follow this growth curve, for reasons that are pretty obvious if you think about all the things that can affect a population.[14]

Nevertheless, the logistic curve has been used for most long-term forecasts of the size of human populations in specific nations. As we said, this S-shaped curve first rises steeply upward and then changes slope, curving toward the horizontal carrying capacity. The point at which the curve changes is the **inflection point**, and until a population has reached this point, we cannot project its final logistic size. The human population had not yet made the bend around the inflection point, but forecasters typically dealt with this problem by assuming that the population was just reaching the inflection point at the time the forecast was made. This standard practice inevitably led to a great underestimate of the maximum population. For example, one of the first projections of the upper limit of the U.S. population, made in the 1930s, assumed that the inflection point had been reached then. That assumption resulted in an estimate that the final population of the United States would be approximately 200 million.[15]

Fortunately for us, Figure 4.5 suggests that our species' growth rate has declined consistently since the 1960s, as we noted before, and therefore we can make projections using the logistic, assuming that we have passed the inflection point. The United Nations has made a series of projections based on current birth rates and death rates and assumptions about how these rates will change. These projections form the basis for the curves presented in Figure 4.6. The logistic projections assume that (1) mortality will fall everywhere and level off when female life expectancy reaches 82 years; (2) fertility will reach replacement levels everywhere between 2005 and 2060; and (3) there will be no worldwide catastrophe. This approach projects an equilibrium world population of 10.1–12.5 billion.[16] Developed nations would experience population growth from 1.2 billion today to 1.9 billion, but populations in developing nations would increase from 4.5 billion to 9.6 billion. Bangladesh (an area the size of Wisconsin) would reach 257 million; Nigeria, 453 million; and India, 1.86 billion. In these projections, the developing countries contribute 95% of the increase.[14]

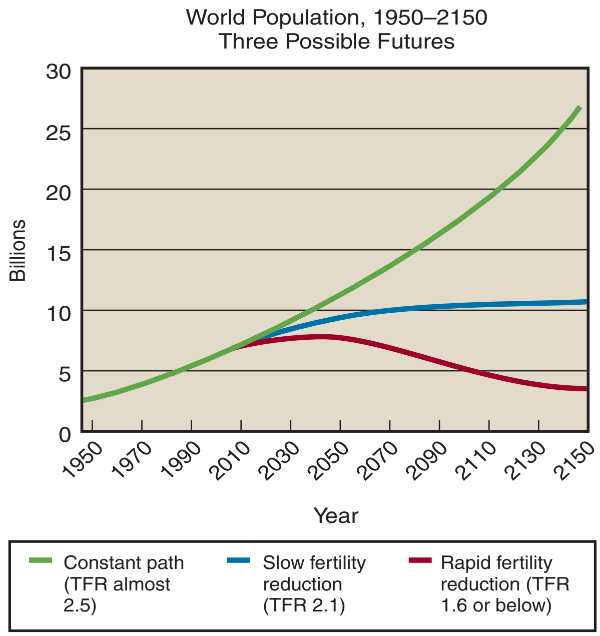


FIGURE 4.6 U.N. projections of world population growth based on the logistic curve and using different total fertility rates (the expected number of children a woman will have during her life—see Chapter 3. The constant path assumes the 1998 growth rate will continue unchanged, resulting in an exponential increase. The slow-fertility-reduction path assumes the world's fertility will decline, reaching replacement level by 2050, so the world's population will stabilize at about 11 billion by the 22nd century. The rapid-fertility-reduction path assumes the total fertility rate will go into decline in the 21st century, with the population peaking at 7.7 billion in 2050 and dropping to 3.6 billion by 2150. These are theoretical curves. The total fertility rate has remained high and is now 2.7. (*Source:* U.S. Census Bureau, *Global Population Profile: 2002*, Table A-10,. p.1. http://www.census.gov/ipc/prod/wp02/tabA-10.pdf).

4.3 Age Structure

As we noted earlier, the two standard methods for forecasting human population growth—the exponential and the logistic—ignore all characteristics of the environment and in that way are seriously incomplete. A more comprehensive approach would take into account the effects of the supply of food, water, and shelter; the prevalence of diseases; and other factors that can affect birth and death rates. But with long-lived organisms like ourselves, these environmental factors have different effects on different age groups, and so the next step is to find a way to express how a population is divided among ages. This is known as the population age structure, which is the proportion of the population of each age group. The age structure of a population affects current and future birth rates, death rates, and growth rates; has an impact on the environment; and has implications for current and future social and economic conditions.

We can picture a population's age structure as a pile of blocks, one for each age group, with the size of each block representing the number of people in that group (Figure 4.7). Although age structures can take many shapes, four general types are most important to our discussion: a pyramid, a column, an inverted pyramid (top-heavy), and a column with a bulge. The pyramid age structure occurs in a population that has many young people and a high death rate at each age—and therefore a high birth rate, characteristic of a rapidly growing population and also of a population with a relatively short average lifetime. A column shape occurs where the birth rate and death rate are low and a high percentage of the population is elderly. A bulge occurs if some event in the past caused a high birth rate or death rate for some age group but not others. An inverted pyramid occurs when a population has more older than younger people.

Age structure varies considerably by nation (Figure 4.7) and provides insight into a population's history, its current status, and its likely future. Kenya's pyramid-shaped age structure reveals a rapidly growing population heavily weighted toward youth. In developing

A CLOSER LOOK 4.2

The Prophecy of Malthus

Almost 200 years ago, the English economist Thomas Malthus eloquently stated the human population problem. His writings have gone in and out of fashion, and some people think his views may be out-of-date, but in 2008 Malthus was suddenly back on the front page, the focus of major articles in the *New York Times*[17] and the *Wall Street Journal*, among other places. Perhaps this is because recent events—from natural catastrophes in Asia to rising prices for oil, food, and goods in general—suggest that the human population problem really is a problem.

Malthus based his argument on three simple premises: [18]

- **Food is necessary for people to survive.**
- **"Passion between the sexes is necessary and will remain nearly in its present state"—so children will continue to be born.**
- **The power of population growth is infinitely greater than the power of Earth to produce subsistence.**

Malthus reasoned that it would be impossible to maintain a rapidly multiplying human population on a finite resource base. His projections of the ultimate fate of humankind were dire, as dismal a picture as that painted by today's most extreme pessimists. The power of population growth is so great, he wrote, that "premature death must in some shape or other visit the human race. The vices of mankind are active and able ministers of depopulation, but should they fail, sickly seasons, epidemics, pestilence and plague, advance in terrific array, and sweep off their thousands and ten thousands." Should even these fail, he said, "gigantic famine stalks in the rear, and with one mighty blow, levels the population with the food of the world."

Malthus's statements are quite straightforward. From the perspective of modern science, they simply point out that in a finite world nothing can grow or expand forever, not even the population of the smartest species ever to live on Earth. Critics of Malthus continue to point out that his predictions have yet to come true, that whenever things have looked bleak, technology has provided a way out, allowing us to live at greater densities. Our technologies, they insist, will continue to save us from a Malthusian fate, so we needn't worry about human population growth. Supporters of Malthus respond by reminding them of the limits of a finite world.

Who is correct? Ultimately, in a finite world, Malthus must be correct about the final outcome of unchecked growth. He may have been wrong about the timing; he did not anticipate the capability of technological changes to delay the inevitable. But although some people believe that Earth can support many more people than it does now, in the long run there must be an upper limit. The basic issue that confronts us is this: How can we achieve a constant world population, or at least halt the increase in population, in a way most beneficial to most people? This is undoubtedly one of the most important questions that has ever faced humanity, and it is coming home to roost now.

Recent medical advances in our understanding of aging, along with the potential of new biotechnology to increase both the average longevity and maximum lifetime of human beings, have major implications for the growth of the human population. As medical advances continue to take place, the death rate will drop and the growth rate will rise even more. Thus, a prospect that is positive from the individual's point of view—a longer, healthier, and more active life—could have negative effects on the environment. We will therefore ultimately face the following choices: Stop medical research into chronic diseases of old age and other attempts to increase people's maximum lifetime; reduce the birth rate; or do neither and wait for Malthus's projections to come true—for famine, environmental catastrophes, and epidemic diseases to cause large and sporadic episodes of human death. The first choice seems inhumane, but the second is highly controversial, so doing nothing and waiting for Malthus's projections may be what actually happens, a future that nobody wants. For the people of the world, this is one of the most important issues concerning science and values and people and nature.

countries today, about 34% of the populations are under 15 years of age. Such an age structure indicates that the population will grow very rapidly in the future, when the young reach marriage and reproductive ages, and it suggests that the future for such a nation requires more jobs for the young. This type of age structure has many other social implications that go beyond the scope of this book.

In contrast, the age structure of the United States is more like a column, showing a population with slow growth, while Japan's top-heavy pyramid shows a nation with declining growth.[8] The U.S. age struc-

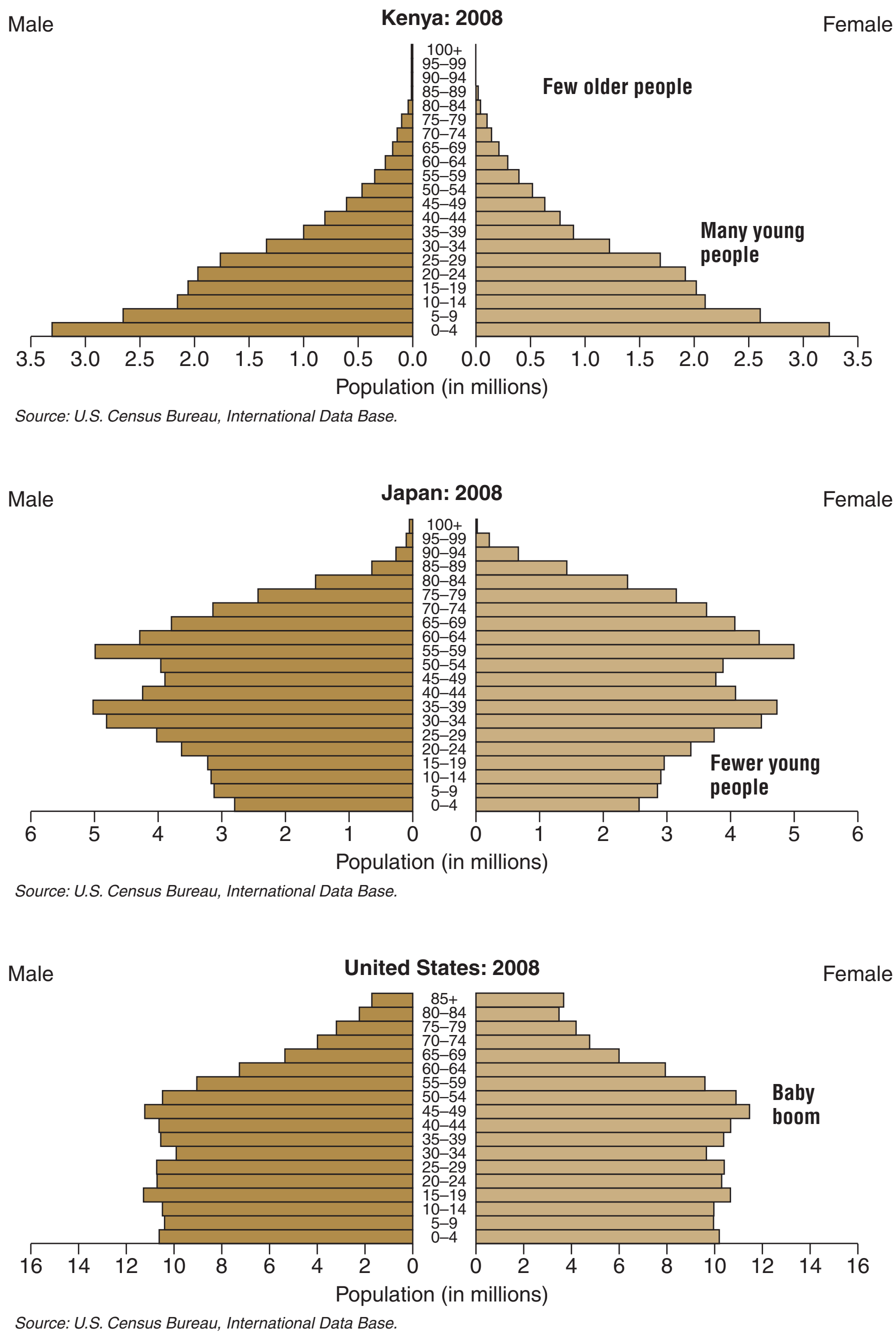


FIGURE 4.7 **Age structure of Kenya, the United States, and Japan, 2008.** The bars to the left are males; those to the right are females. (*Source*: U.S. Bureau of the Census.)

ture also shows the baby boom that occurred in the United States after World War II; a great increase in births from 1946 through 1964 forms a pulse in the population that can be seen as a bulge in the age structure, especially of those aged 45–55 in 2008. At each age, the baby boomers increased demand for social and economic resources; for example, schools were crowded when the baby boomers were of primary- and secondary-school age.

4.4 The Demographic Transition

The **demographic transition** is a three-stage pattern of change in birth rates and death rates that has occurred during the process of industrial and economic development of Western nations. It leads to a decline in population growth.

A decline in the death rate is the first stage of the demographic transition (Figure 4.8).[7] In a nonindustrial country, birth rates and death rates are high, and the growth rate is low. With industrialization, health and sanitation improve and the death rate drops rapidly. The birth rate remains high, however, and the population enters Stage II, a period with a high growth rate. Most European nations passed through this period in the 18th and 19th centuries. As education and the standard of living increase and as family-planning methods become more widely used, the population reaches Stage III. The birth rate drops toward the death rate, and the growth rate therefore declines, eventually to a low or zero growth rate. However, the birth rate declines only if families believe there is a direct connection between future economic well-being and funds spent on the education and care of their young. Such families have few children and put all their resources toward the education and well-being of those few.

Historically, parents have preferred to have large families. Without other means of support, aging parents can depend on grown children for a kind of "social security," and even young children help with many kinds of hunting, gathering, and low-technology farming. Unless there is a change in attitude among parents—unless they see more benefits from a few well-educated children than from many poorer children—nations face a problem in making the transition from Stage II to Stage III (see Figure 4.8c).

Some developed countries are approaching Stage III, but it is an open question whether developing nations will make the transition before a serious population crash occurs. *The key point here is that the demographic transition will take place only if parents come to believe that having a small family is to their*

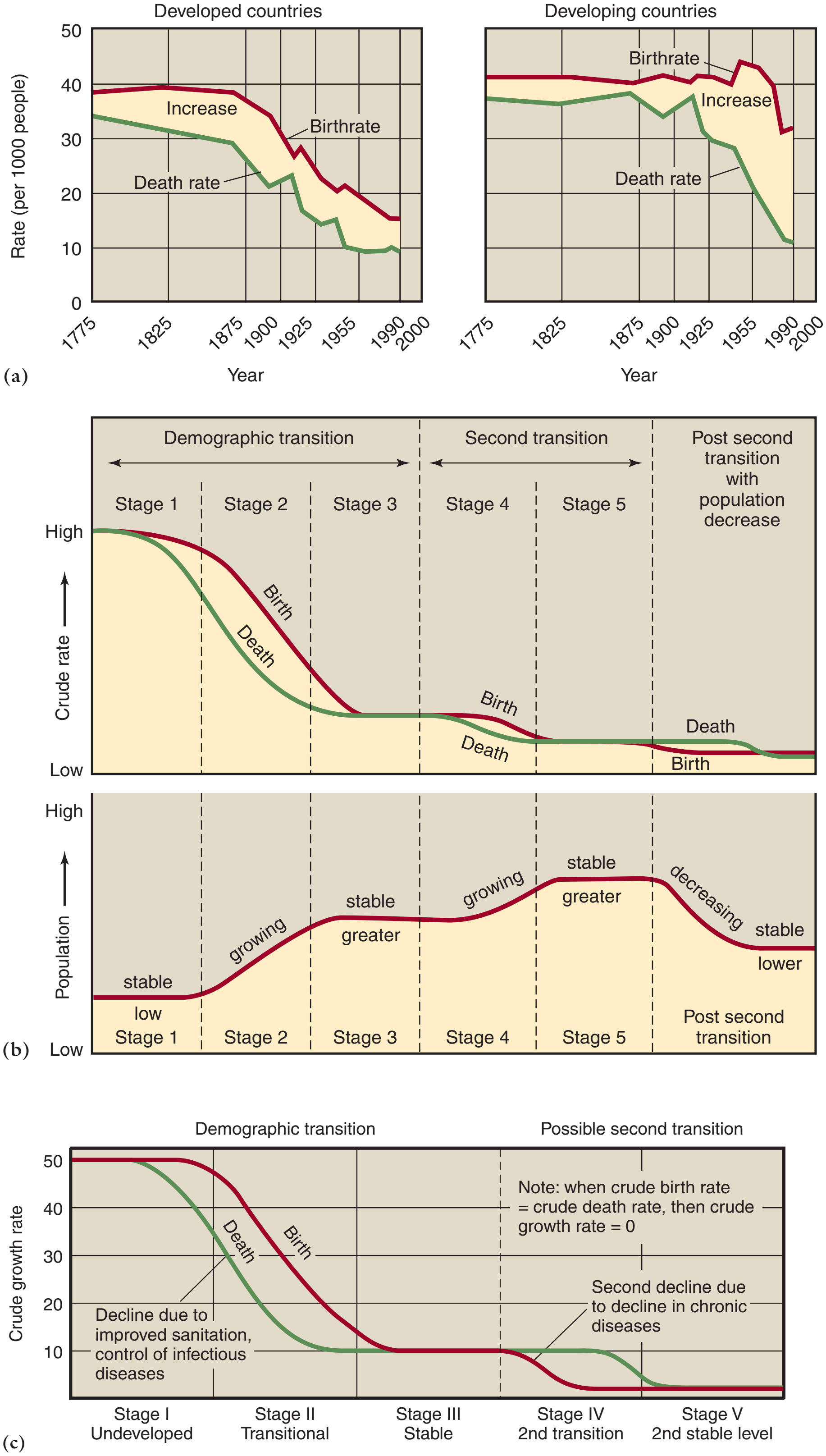


FIGURE 4.8 The demographic transition: (a) Theoretical, including possible fourth and fifth stages that might take place in the future; **(b)** the resulting relative change in population; **(c)** the change in birth rates and death rates from 1775 to 2000 in developed and developing countries. (*Source:* M.M. Kent and K.A. Crews, *World Population: Fundamentals of Growth* [Washington, DC: Population Reference Bureau, 1990]. Copyright 1990 by the Population Reference Bureau, Inc. Reprinted by permission.)

benefit. Here we again see the connection between science and values. Scientific analysis can show the value of small families, but this knowledge must become part of cultural values to have an effect.

Potential Effects of Medical Advances on the Demographic Transition

Although the demographic transition is traditionally defined as consisting of three stages, advances in treating chronic health problems such as heart disease can lead a Stage III country to a second decline in the death rate. This could bring about a second transitional phase of population growth (Stage IV), in which the birth rate would remain the same while the death rate fell. A second stable phase of low or zero growth (Stage V) would be achieved only when the birth rate declined even further to match the decline in the death rate. Thus, there is danger of a new spurt of growth even in industrialized nations that have passed through the standard demographic transition.

4.5 Longevity and Its Effect on Population Growth

The **maximum lifetime** is the genetically determined maximum possible age to which an individual of a species *can* live. **Life expectancy** is the average number of years an individual *can expect* to live given the individual's present age. Technically, life expectancy is an age-specific number: Each age class within a population has its own life expectancy. For general comparison, however, we use the life expectancy at birth.

Life expectancy is much higher in developed, more prosperous nations. Nationally, the highest life expectancy is 84 years, in the tiny nation of Macau. Of the major nations, Japan has the highest life expectancy, 82.1 years. Sixteen other nations have a life expectancy of 80 years or more: Singapore, Hong Kong, Australia, Canada, France, Guernsey, Sweden, Switzerland, Israel, Anguilla, Iceland, Bermuda, Cayman Islands, New Zealand, Gibraltar, and Italy. The United States, one of the richest countries in the world, ranks 50th among nations in life expectancy, at 78 years. China has a life expectancy of just over 73 years; India just over 69 years. Swaziland has the lowest of all nations at 32 years. The ten nations with the shortest life expectancies are all in Africa.[19] Not surprisingly, there is a relationship between per capita income and life expectancy.

A surprising aspect of the second and third periods in the history of human population is that population growth occurred with little or no change in the maximum lifetime. What changed were birth rates, death rates, population growth rates, age structure, and average life expectancy.

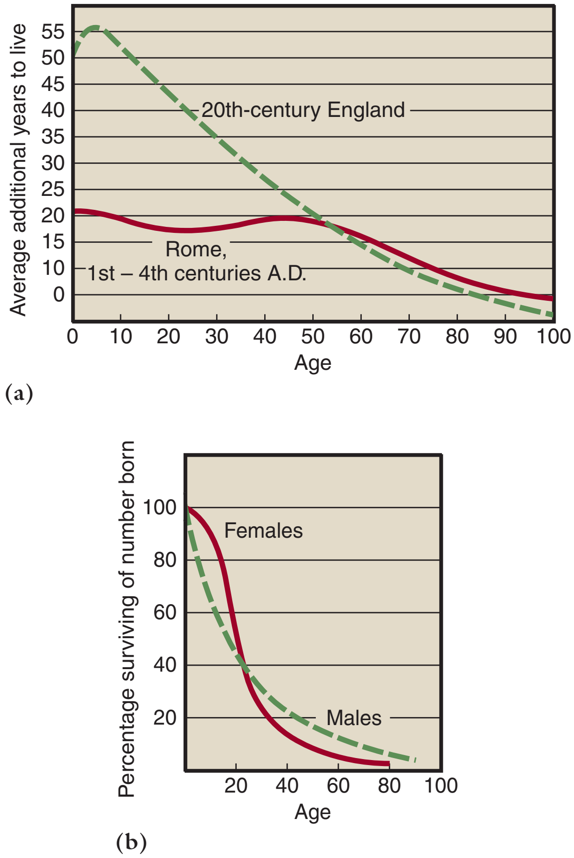


FIGURE 4.9 (a). Life expectancy in ancient Rome and 20th-century England. This graph shows the average number of years one could expect to live after reaching a given age: for example, a 10-year-old in England could expect to live about 55 more years; a 10-year-old in Rome, about 20 more years. Life expectancy was greater in 20th-century England than in ancient Rome until about age 55. An 80-year-old Roman could expect to live longer than an 80-year-old Briton. Data for Romans is reconstructed from ages on tombstones. **(b)**. Approximate survivorship curve for Rome for the first four centuries C.E. The percentage surviving drops rapidly in the early years, reflecting high mortality rates for children in ancient Rome. Females had a slightly higher survivorship rate until age 20, after which males had a slightly higher rate. (*Source*: Modified from G.E. Hutchinson, *An Introduction to Population Ecology* [New Haven, CT: Yale University Press, 1978]. Copyright 1978 by Yale University Press. Used by permission.)

Ages at death, from information carved on tombstones, tell us that the chances of a 75-year-old living to age 90 were greater in ancient Rome than they are today in England (Figure 4.9). These also suggest that death rates were much higher in Rome than in 20th-century England. In ancient Rome, the life expectancy of a 1-year-old was about 22 years, while in 20th-century England it was about 50 years. Life expectancy in 20th-century England was greater than in ancient Rome for all ages until age 55, after which it appears to have been higher for ancient Romans than for 20th-century Britons. This suggests that many hazards of modern life may be concentrated more on the aged. Pollution-induced diseases are one factor in this change.

Human Death Rates and the Rise of Industrial Societies

We return now to further consideration of the first stage in the demographic transition. We can get an idea of the first stage by comparing a modern industrialized country, such as Switzerland, which has a crude death rate of 8.59 per 1,000, with a developing nation, such as Sierra Leone, which has a crude death rate of 21.9.[20] Modern medicine has greatly reduced death rates from disease in countries such as Switzerland, particularly with respect to death from acute or epidemic diseases, such as flu, SARS, and West Nile virus, which we discussed in the chapter's opening case study.

An **acute disease** or **epidemic disease** appears rapidly in the population, affects a comparatively large percentage of it, and then declines or almost disappears for a while, only to reappear later. Epidemic diseases typically are rare but have occasional outbreaks during which a large proportion of the population is infected. A **chronic disease**, in contrast, is always present in a population, typically occurring in a relatively small but relatively constant percentage of the population. Heart disease, cancer, and stroke are examples.

The great decrease in the percentage of deaths due to acute or epidemic diseases can be seen in a comparison of causes of deaths in Ecuador in 1987 and in the United States in 1900, 1987, and 1998 (Figure 4.10).[21] In Ecuador, a developing nation, acute diseases and those listed as "all others" accounted for about 60% of mortality in 1987. In the United States in 1987, these accounted for only 20% of mortality. Chronic diseases account for about 70% of mortality in the modern United States. In

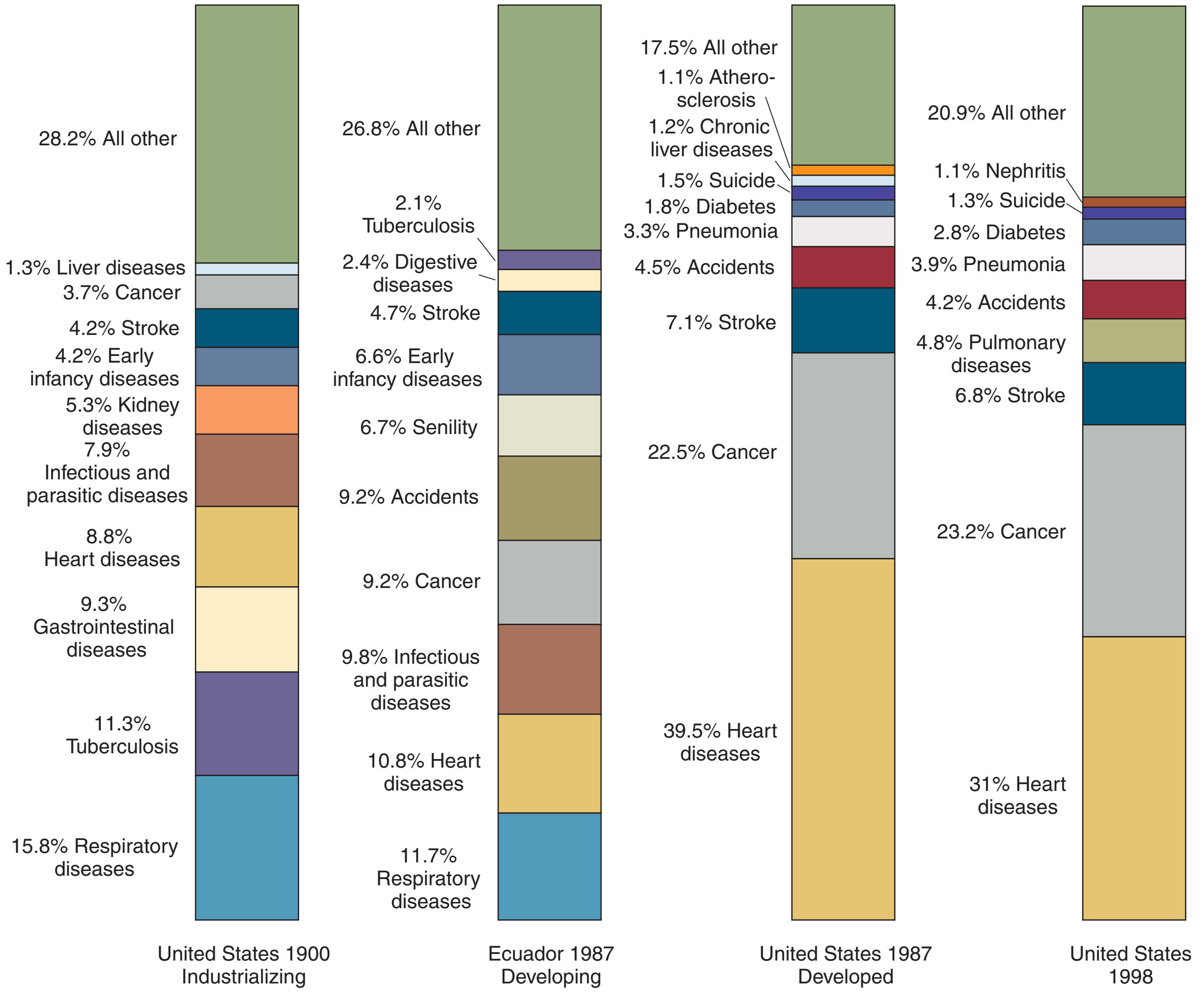


FIGURE 4.10 Causes of mortality in industrializing, developing, and industrialized nations. (*Sources:* U.S. 1900, Ecuador 1987, and U.S. 1987 data from M.M. Kent and K. A. Crews, *World Population: Fundamentals of Growth* [Washington, DC: Population Reference Bureau, 1990]. Copyright 1990 by the Population Reference Bureau, Inc. Reprinted by permission. *National Vital Statistics Report* 48 [11], July 24, 2000.)

contrast, chronic diseases accounted for less than 20% of the deaths in the United States in 1900 and about 33% in Ecuador in 1987. Ecuador in 1987, then, resembled the United States of 1900 more than it resembled the United States of either 1987 or 1998.

4.6 The Human Population's Effects on the Earth

The danger that the human population poses to the environment is the result of two factors: the number of people and the environmental impact of each person. When there were few people on Earth and limited technology, the human impact was primarily local. Even so, people have affected the environment for a surprisingly long time. It started with the use of fire to clear land, and it continued, new research shows, with large effects on the environment by early civilizations. For example, the Mayan temples in South America, standing now in the midst of what were recently believed to be ancient rain forests, actually stood in large areas of farmed land cleared by the Maya. Large areas of North America were modified by American Indians, who used fire for a variety of reasons and modified the forests of the eastern United States.[22] The problem now is that there are so many people and our technologies are so powerful that our effects on the environment are even more global and significant. This could cause a negative feedback—the more people, the worse the environment; the worse the environment, the fewer people.

The simplest way to characterize the total impact of the human population on the environment is to multiply the average impact of an individual by the total number of individuals,[23] or

$$T = P \times I$$

where P is the population size—the number of people—and I is the average environmental impact per person. Of course, the impact per person varies widely, within the same nation and also among nations. The average impact of a person who lives in the United States is much greater than the impact of a person who lives in a low-technology society. But even in a poor, low-technology nation like Bangladesh, the sheer number of people leads to large-scale environmental effects.

Modern technology increases the use of resources and enables us to affect the environment in many new ways, compared with hunters and gatherers or people who farmed with simple wooden and stone tools. For example, before the invention of chlorofluorocarbons (CFCs), which are used as propellants in spray cans and as coolants in refrigerators and air conditioners, we were not causing depletion of the ozone layer in the upper atmosphere. Similarly, before we started driving automobiles, there was much less demand for steel, little demand for oil, and much less air pollution. These linkages between people and the global environment illustrate the global theme and the people-and-nature theme of this book.

The population-times-technology equation reveals a great irony involving two standard goals of international aid: improving the standard of living and slowing overall human population growth. Improving the standard of living increases the total environmental impact, countering the environmental benefits of a decline in population growth.

4.7 The Human Carrying Capacity of Earth

What is the **human carrying capacity** of Earth—that is, how many people can live on Earth at the same time? The answer depends on what quality of life people desire and are willing to accept.

As we have made clear in this chapter, on our finite planet the human population will eventually be limited by some factor or combination of factors. We can group limiting factors into those that affect a population during the year in which they become limiting (short-term factors), those whose effects are apparent after one year but before ten years (intermediate-term factors), and those whose effects are not apparent for ten years (long-term factors). Some factors fit into more than one category, having, say, both short-term and intermediate-term effects.

An important *short-term* factor is the disruption of food distribution in a country, commonly caused by drought or by a shortage of energy for transporting food.

Intermediate-term factors include desertification; dispersal of certain pollutants, such as toxic metals, into waters and fisheries; disruption in the supply of nonrenewable resources, such as rare metals used in making steel alloys for transportation machinery; and a decrease in the supply of firewood or other fuels for heating and cooking.

Long-term factors include soil erosion, a decline in groundwater supplies, and climate change. A decline in resources available per person suggests that we may already have exceeded Earth's long-term human carrying capacity. For example, wood production peaked at 0.67 m^3/person (0.88 yd^3/person) in 1967, fish production at 5.5 kg/person (12.1 lb/person) in 1970, beef at 11.81 kg/person (26.0 lb/person) in 1977, mutton at 1.92 kg/person (4.21 lb/person) in 1972, wool at

0.86 kg/person (1.9 lb/person) in 1960, and cereal crops at 342 kg/person (754.1 lb/person) in 1977.[24] Before these peaks were reached, per capita production of each resource had grown rapidly.

Since the rise of the modern environmental movement in the second half of the 20th century, much attention has focused on estimating the human carrying capacity of Earth—the total number of people that our planet could support indefinitely. This estimation has typically involved three methods. One method, which we have already discussed, is to simply extrapolate from past growth, assuming that the population will follow an S-shaped logistic growth curve and gradually level off (Figure 4.6).

The second method can be referred to as the packing-problem approach. This method simply considers how many people might be packed onto Earth, not taking into sufficient account the need for land and oceans to provide food, water, energy, construction materials, the need to maintain biological diversity, and the human need for scenic beauty. This approach, which could also be called the standing-room-only approach, has led to very high estimates of the total number of people that might occupy Earth—as many as 50 billion.

More recently, a philosophical movement has developed at the other extreme. Known as deep ecology, this third method makes sustaining the biosphere the primary moral imperative. Its proponents argue that the whole Earth is necessary to sustain life, and therefore everything else must be sacrificed to the goal of sustaining the biosphere. People are considered active agents of destruction of the biosphere, and therefore the total number of people should be greatly reduced.[25] Estimates based on this rationale for the desirable number of people vary greatly, from a few million up.

Between the packing-problem approach and the deep-ecology approach are a number of options. It is possible to set goals in between these extremes, but each of these goals is a value judgment, again reminding us of one of this book's themes: *science and values*. What constitutes a desirable quality of life is a value judgment. The perception of what is desirable will depend in part on what we are used to, and this varies greatly. For example, in the United States, New Jersey has only a half acre (0.22 ha) per person, while Wyoming, the most sparsely populated of the lower 48 states, has 116 acres (47.2 ha) per person. For comparison, New York City's Manhattan Island has 71,000 people per square mile, which works out to an area of about 20 × 20 feet per person. Manhattanites manage to live comfortably by using not just the land area but also the airspace to a considerable height. Still, it's clear that people used to living in Wyoming and people living in New Jersey or in Manhattan skyscrapers are likely to have very different views on what is a desirable population density.

Moreover, what quality of life is possible depends not just on the amount of space available but also on technology, which in turn is affected by science. Scientific understanding also tells us what is required to meet each quality-of-life level. The options vary. If all the people of the world were to live at the same level as those of the United States, with our high resource use, then the carrying capacity would be comparatively low. If all the people of the world were to live at the level of those in Bangladesh, with all of its risks as well as its poverty and its heavy drain on biological diversity and scenic beauty, the carrying capacity would be much higher.

In summary, the acceptable carrying capacity is not simply a scientific issue; it is an issue combining science and values, within which science plays two roles. First, by leading to new knowledge, which in turn leads to new technology, it makes possible both a greater impact per individual on Earth's resources and a higher density of human beings. Second, scientific methods can be used to forecast a probable carrying capacity once a goal for the average quality of life, in terms of human values, is chosen. In this second use, science can tell us the implications of our value judgments, but it cannot provide those value judgments.

4.8 Can We Achieve Zero Population Growth?

We have surveyed several aspects of population dynamics. The underlying question is: Can we achieve **zero population growth**—a condition in which the human population, on average, neither increases nor decreases? Much of environmental concern has focused on how to lower the human birth rate and decrease our population growth. As with any long-lived animal population, our species could take several possible approaches to achieving zero population growth. Here are a few.

Age of First Childbearing

The simplest and one of the most effective means of slowing population growth is to delay the age of first childbearing.[26] As more women enter the workforce and as education levels and standards of living rise, this delay occurs naturally. Social pressures that lead to deferred marriage and childbearing can also be effective (Figure 4.11).

FIGURE 4.11 As more and more women enter the workforce and establish professional careers, the average age of first childbearing tends to rise. The combination of an active lifestyle that includes children is illustrated here by the young mother jogging with her child in Perth, Australia.

Typically, countries where early marriage is common have high population growth rates. In South Asia and in Sub-Saharan Africa, about 50% of women marry between the ages of 15 and 19, and in Bangladesh women marry on average at age 16. In Sri Lanka, however, the average age for marriage is 25. The World Bank estimates that if Bangladesh adopted Sri Lanka's marriage pattern, families could average 2.2 fewer children.[26] For many countries, raising the marriage age could account for 40–50% of the drop in fertility required to achieve zero population growth.

Birth Control: Biological and Societal

Another simple way to lower the birth rate is breast feeding, which can delay resumption of ovulation after childbirth.[27] Women in a number of countries use this deliberately as a birth-control method—in fact, according to the World Bank, in the mid-1970s breast feeding provided more protection against conception in developing countries than did family-planning programs.[26]

Family planning is still emphasized, however.[28] Traditional methods range from abstinence to the use of natural agents to induced sterility. Modern methods include the birth-control pill, which prevents ovulation through control of hormone levels; surgical techniques for permanent sterility; and mechanical devices. Contraceptive devices are used widely in many parts of the world, especially in East Asia, where data show that 78% of women use them. In Africa, only 18% of women use them; in Central and South America, the numbers are 53% and 62%, respectively.[26] Abortion is also widespread and is one of the most important birth-control methods in terms of its effects on birth rates—approximately 46 million abortions are performed each year.[29] However, although now medically safe in most cases, abortion is one of the most controversial methods from a moral perspective.

National Programs to Reduce Birth Rates

Reducing birth rates requires a change in attitude, knowledge of the means of birth control, and the ability to afford these means. As we have seen, a change in attitude can occur simply with a rise in the standard of living. In many countries, however, it has been necessary to provide formal family-planning programs to explain the problems arising from rapid population growth and to describe the ways that individuals will benefit from reduced population growth. These programs also provide information about birth-control methods and provide access to these methods.[30] Which methods to promote and use involves social, moral, and religious beliefs, which vary from country to country.

The first country to adopt an official population policy was India in 1952. Few developing countries had official family-planning programs before 1965. Since 1965, many such programs have been introduced, and the World Bank has lent $4.2 billion to more than 80 countries to support "reproductive" health projects.[26,31] Although most countries now have some kind of family-planning program, effectiveness varies greatly.

A wide range of approaches have been used, from simply providing more information to promoting and providing means for birth control, offering rewards, and imposing penalties. Penalties usually take the form of taxes. Ghana, Malaysia, Pakistan, Singapore, and the Philippines have used a combination of methods, including limits on tax allowances for children and on maternity benefits. Tanzania has restricted paid maternity leave for women to a frequency of once in three years. Singapore does not take family size into account in allocating government-built housing, so larger families are more crowded. Singapore also gives higher priority in school admission to children from smaller families. Some countries, including Bangladesh, India, and Sri Lanka, have paid people to be voluntarily sterilized. In Sri Lanka, this practice has applied only to families with two children, and only when a voluntary statement of consent is signed.

CRITICAL THINKING ISSUE

Will the Demographic Transition Hold in the United States?

Earlier in this chapter, we presented the idea of the demographic transition and suggested that it has occurred in developed nations and may continue in the future. But we also noted that improvements in health care can further decrease death rates, which is something everybody wants to see happen but which will increase the human population growth rate, even in technologically developed nations. Recently, Robert Engelman, a vice president of the Worldwatch Institute of Washington, DC, proposed another problem for the demographic transition—an increase in birth rates in nations such as the United States.[32] The accompanying text box has selections from Engelman's article. Using the material in the chapter, the quotes from Engelman here, and any other information you would like to introduce, present an argument either for or against the following: Growth rates will continue to decline in technologically developed nations, leading toward zero population growth.

Robert Engelman, Vice President of the Worldwatch Institute, "World Population Growth: Fertile Ground for Uncertainty," 2008.

Although the average woman worldwide is giving birth to fewer children than ever before, an estimated 136 million babies were born in 2007. Global data do not allow demographers to be certain that any specific year sets a record for births, but this one certainly came close. The year's cohort of babies propelled global population to an estimated 6.7 billion by the end of 2007.

The seeming contradiction between smaller-than-ever families and near-record births is easily explained. The number of women of childbearing age keeps growing and global life expectancy at birth continues to rise. These two trends explain why population continues growing despite declines in family size. There were 1.7 billion women aged 15 to 49 in late 2007, compared with 856 million in 1970. The average human being born today can expect to live 67 years, a full decade longer than the average newborn could expect in 1970.

Only the future growth of the reproductive-age population is readily predictable, however: all but the youngest of the women who will be in this age group in two decades are already alive today. But sustaining further declines in childbearing and increases in life expectancy will require continued efforts by governments to improve access to good health care, and both trends could be threatened by environmental or social deterioration. The uncertain future of these factors makes population growth harder to predict than most people realize.

SUMMARY

- The human population is often referred to as the underlying environmental issue because much current environmental damage results from the very high number of people on Earth and their great power to change the environment.
- Throughout most of our history, the human population and its average growth rate were small. The growth of the human population can be divided into four major phases. Although the population has increased in each phase, the current situation is unprecedented.
- Countries whose birth rates have declined have experienced a demographic transition marked by a decline in death rates followed by a decline in birth rates. In contrast, many developing nations have undergone a great decline in their death rates but still have very high birth rates. It remains an open question whether some of these nations will be able to achieve a lower birth rate before reaching disastrously high population levels.
- The maximum population Earth can sustain and how large a population will ultimately be attained by human beings are controversial questions. Standard estimates

suggest that the human population will reach 10–16 billion before stabilizing.

- How the human population might stabilize, or be stabilized, raises questions concerning science, values, people, and nature.
- One of the most effective ways to lower a population's growth rate is to lower the age of first childbearing. This approach also involves relatively few societal and value issues.

REEXAMINING THEMES AND ISSUES

Human Population

Our discussion in this chapter reemphasizes the point that there can be no long-term solution to our environmental problems unless the human population stops growing at its present rate. This makes the problem of human population a top priority.

Sustainability

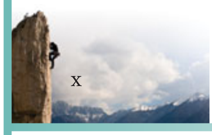
As long as the human population continues to grow, it is doubtful that our other environmental resources can be made sustainable.

Global Perspective

Although the growth rate of the human population varies from nation to nation, the overall environmental effects of the rapidly growing human population are global. For example, the increased use of fossil fuels in Western nations since the beginning of the Industrial Revolution has affected the entire world. The growing demand for fossil fuels and their increasing use in developing nations are also having a global effect.

Urban World

One of the major patterns in the growth of the human population is the increasing urbanization of the world. Cities are not self-contained but are linked to the surrounding environment, depending on it for resources and affecting environments elsewhere.



People and Nature

As with any species, the growth rate of the human population is governed by fundamental laws of population dynamics. We cannot escape these basic rules of nature. People greatly affect the environment, and the idea that human population growth is *the* underlying environmental issue illustrates the deep connection between people and nature.

Science and Values

The problem of human population exemplifies the connection between values and knowledge. Scientific and technological knowledge has helped us cure diseases, reduce death rates, and thereby increase growth of the human population. Our ability today to forecast human population growth provides a great deal of useful knowledge, but what we do with this knowledge is hotly debated around the world because values are so important in relation to birth control and family size.

KEY TERMS

STUDY QUESTIONS

1. Refer to three forecasts for the future of the world's human population in Figure 4.6. Each forecast makes a different assumption about the future total fertility rate: that the rate remains constant; that it decreases slowly and smoothly; and that it decreases rapidly and smoothly. Which of these do you think is realistic? Explain why.

2. Why is it important to consider the age structure of a human population?

3. Three characteristics of a population are the birth rate, growth rate, and death rate. How has each been affected by (a) modern medicine, (b) modern agriculture, and (c) modern industry?

4. What is meant by the statement "What is good for an individual is not always good for a population"?

5. Strictly from a biological point of view, why is it difficult for a human population to achieve a constant size?

6. What environmental factors are likely to increase the chances of an outbreak of an epidemic disease?

7. To which of the following can we attribute the great increase in human population since the beginning of the Industrial Revolution: changes in human (a) birth rates, (b) death rates, (c) longevity, or (d) death rates among the very old? Explain.

8. What is the demographic transition? When would one expect replacement-level fertility to be achieved—before, during, or after the demographic transition?

9. Based on the history of human populations in various countries, how would you expect the following to change as per capita income increased: (a) birth rates, (b) death rates, (c) average family size, and (d) age structure of the population? Explain.

FURTHER READING

Barry, J.M., *The Great Influenza: The Story of the Deadliest Pandemic in History* (New York: Penguin Books, paperback, 2005). Written for the general reader but praised by such authorities as the *New England Journal of Medicine,* this book discusses the connection between politics, public health, and pandemics.

Cohen, J.E., *How Many People Can the Earth Support?* (New York: Norton, 1995). A detailed discussion of world population growth, Earth's human carrying capacity, and factors affecting both.

Ehrlich, P.R., and A.H. Ehrlich, *One with Nineveh: Politics, Consumption, and the Human Future* (Washington, DC: Island Press, 2004). An extended discussion of the effects of the human population on the world's resources, and of Earth's carrying capacity for our species. Ehrlich's 1968 book, *The Population Bomb* (New York: Ballantine Books), played an important role in the beginning of the modern environmental movement, and for this reason can be considered a classic.

Livi-Bacci, Massimo, A *Concise History of World Population* (Hoboken, NJ: Wiley-Blackwell, paperback, 2001). A well-written introduction to the field of human demography.

McKee, J.K., *Sparing Nature: The Conflict between Human Population Growth and Earth's Biodiversity* (New Brunswick, NJ: Rutgers University Press, 2003). One of the few recent books about human populations.