Populations

6

POPULATION ECOLOGY

Population ecology studies the dynamics of species' populations and how these populations interact with the environment. Most organisms live in groups (flocks, schools, nests, etc.) and living in groups provides several advantages: increased protection from predators, increased chances for mating, and division of labor.

Population ecology plays an important role in the development of the field of conservation biology, especially in predicting the long-term probability of a species persisting in a given habitat.

Biotic Potential

Biotic potential is the maximum reproductive capacity of an organism under optimum environmental conditions (e.g., sufficient food supply, no predators, lack of disease). An organism's rate of reproduction and the size of each litter are the primary determining factors for biotic potential.

Biotic potential is often expressed as a percentage increase per year (e.g., "The human population increased by 3% last year."). It can also be expressed as the time it takes for a population to double in size (doubling time).

Significant differences in biotic potential exist between species (e.g., many large mammals, such as humans or elephants, will typically only produce one or two offspring per year while some small organisms, like insects, will produce thousands of offspring per year).

Full expression of the biotic potential of an organism is restricted by environmental resistance, any factor that inhibits an increase in the number of organisms in the population. These limiting factors include unfavorable climatic conditions (e.g., lack of space, light, nutritional deficiencies, and the inhibiting effects of predators, parasites, disease organisms, or unfavorable genetic changes).

Factors That Influence Biotic Potential

Increase Biotic Potential	Decrease Biotic Potential
Favorable environmental conditions (light, temperature, and nutrients)	Unfavorable environmental conditions (insufficient light, temperature extremes, and/or poor supply of nutrients)
High birth rate	Low birth rate
Generalized niche	Specialized niche
Satisfactory habitat	Habitat not satisfactory or has been seriously impacted
Few competitors	Too many competitors
Suitable predatory defense mechanism(s)	Unsuitable predatory defense mechanism(s)
Adequate resistance to diseases and parasites	Little or no suitable defense mechanisms against diseases or parasites
Able to migrate	Unable to migrate
Flexible—able to adapt	Inflexible—unable to adapt
Sufficient food supply	Deficient food supply

Carrying Capacity

Carrying capacity refers to the number of individuals that can be supported in a given area sustainably. It varies from species to species and is subject to changes over time. As an environment degrades, the carrying capacity decreases. Factors that keep population sizes in balance with the carrying capacity are called regulating factors. They include:

- Food availability
- Space
- Oxygen content in aquatic ecosystems
- Nutrient levels in soil profiles
- Amount of sunlight available

Below the carrying capacity, populations tend to increase in size. Population size cannot be sustained above the carrying capacity; eventually the population will crash.

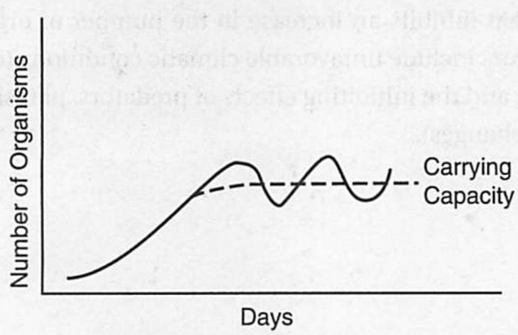


Figure 6.1 Fluctuations around the carrying capacity

J-Curve

A J-curve on a graph records the situation in which, in a new environment, the population density of an organism increases rapidly in an exponential or logarithmic form, but then stops abruptly as environmental resistance (e.g., seasonality) or some other factor (e.g., the end of the breeding phase) suddenly becomes effective. The actual rate of population change depends on the biotic potential and the population size. Population numbers typically show great fluctuation, such as the characteristic "boom and bust" cycles of some insects or the cycles seen in algal blooms. This type of population growth is termed "density independent" as the regulation of growth rate is not tied to the population density until the final crash.

S-Curve

An S-shaped curve of growth (also known as logistical growth) occurs when, in a new environment, the population density of an organism increases slowly initially, in a positive acceleration phase, then increases rapidly, approaching an exponential growth rate as in the J-shaped curve, but then declines in a negative acceleration phase until reaching zero growth when the population stabilizes. This slowing of the rate of growth reflects the increasing environmental resistance which becomes proportionately more important at higher population densities. This type of population growth is termed "density dependent" since the growth rate depends on the numbers present in the population. The point of stabilization, or zero growth rate, is the carrying capacity of the environment for that organism. *K* represents the point at which the upward curve begins to level, produced when changing population numbers are plotted over time.

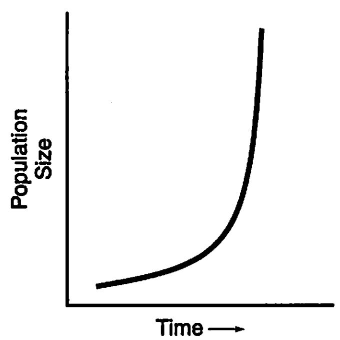


Figure 6.2 J-shaped population curve

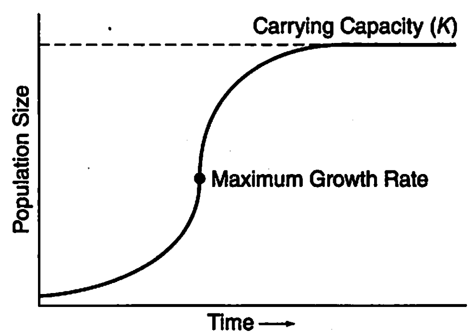


Figure 6.3 S-shaped population curve (logistics model)

Predation

Predation is a mode of life in which food is primarily obtained by the killing and consuming of animals. Predator and prey populations are closely interdependent. Predation not only removes the very old, the very young, and the weaker members from the population, but it may also reduce the population of the prey (e.g., if the predators do not keep the prey population in balance, the carrying capacity is exceeded, and the prey may starve).

Reproductive Strategies

Organisms have adapted either to maximize growth rates in environments that lack limits or to maintain population size at close to the carrying capacity in stable environments. Species that have high reproductive rates are known as *r*-strategists. Species that reproduce later in life and with fewer offspring are known as *K*-strategists.

Reproductive Strategies

r-Strategists	*K*-Strategists
Mature rapidly	Mature slowly
Short lived	Long lived
Tend to be prey	Tend to be both predator and prey
Have many offspring and tend to overproduce	Have few offspring
Low parental care	High parental care
Are generally not endangered	Most endangered species are *K*-strategists
Wide fluctuations in population density (booms and busts)	Population size stabilizes near the carrying capacity
Population size limited by density-independent limiting factors, including climate, weather, natural disasters, and requirements for growth	Density-dependent limiting factors to population growth stem from intraspecific competition and include competition, predation, parasitism, and migration
Tend to be small	Tend to be larger
Type III survivorship curve	Type I or II survivorship curve
Examples: most insects, algae, bacteria, rodents, and annual plants	Examples: humans, elephants, cacti, and sharks

Thomas Malthus

Thomas Malthus was a political economist who was concerned about what he saw as the decline of living conditions in 19th-century England. He blamed this decline on three elements: (1) the overproduction of young; (2) the inability of resources to keep up with the rising human population; and (3) the irresponsibility of the lower classes. To combat this, Malthus suggested the family size of the lower class ought to be regulated such that poor families do not produce more children than they can support. In his 1798 work, *Essay on Population*, Malthus hypothesized that unchecked population growth always exceeds the means of supporting a larger population. He argued that actual population growth is kept in line with food supply by "positive checks" such as starvation, disease, and war, which elevate the death rate, and by "preventive checks" (e.g., postponement of marriage), which keep down the birth rate. Malthus's hypothesis implied that actual population growth always has the tendency to push above the available food supply. Because of this tendency, any attempt to correct the condition of the lower classes by increasing their living standards or improving agricultural productivity would not be possible, as any extra means of subsistence would be completely absorbed by an increase in the population. Charles Darwin incorporated some of Malthus's ideas into his 1859 book, *On the Origin of Species*, by stating that limited resources result in competition, with those organisms that survive being able to pass on those adaptations through their genes to their offspring.

SURVIVORSHIP

Survivorship curves show age distribution characteristics of species, reproductive strategies, and life history. Reproductive success is measured by how many organisms are able to mature and reproduce. Each survivorship curve represents a balance between natural resource limitations and interspecific and intraspecific competition. For example, humans could not survive in a Type III survivorship mode, where human females would produce thousands of offspring. Likewise, ants could not survive in a Type I mode, where each queen ant would produce only a few eggs during her lifetime and where she would spend most of her time and energy raising offspring.

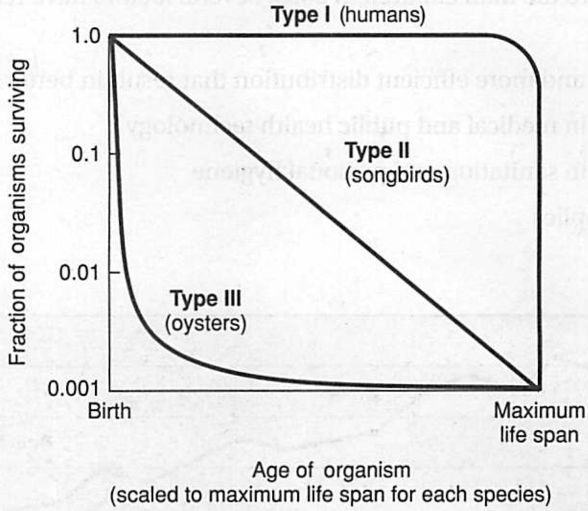


Figure 6.4 Survivorship curve

Survivorship Curves

Type	Description
I. Late Loss	Reproduction occurs fairly early in life. Most deaths occur at the limit of biological life span. Low mortality at birth; high probability of surviving to advanced age. Death rates increase during old age. Advances in prenatal care, nutrition, disease prevention, and cures including immunization have meant longer life spans for humans. Examples: humans, annual plants, sheep, and elephants.
II. Constant Loss	Individuals in all age categories have fairly uniform death rates. Predation affecting all age categories is primary means of death. Typical of organisms that reach adult stages quickly. Examples: rodents, perennial plants, and songbirds.
III. Early Loss	Typical of species that have great numbers of offspring and reproduce for most of their lifetime. Death is prevalent for younger members of the species (environmental loss and predation) and declines with age. Examples: sea turtles, trees, internal parasites, fish, and oysters.

HUMAN POPULATION DYNAMICS

Many different factors, affect the human population: historical population sizes, population distribution, fertility rates, and growth rates and doubling times. Age-structure diagrams act as indicators of future population trends.

Historical Population Sizes

The rapid growth of the world's human population over the past 100 years has been due primarily to a decrease in death rates. In 1900, the overall death rate in the United States was 1.7%. In 2000, the death rate had dropped to 0.9% (almost half). Children in 1900 were 10 times more likely to die than children in 2000. Several factors have reduced human death rates:

- Increased food and more efficient distribution that result in better nutrition
- Improvements in medical and public health technology
- Improvements in sanitation and personal hygiene
- Safer water supplies

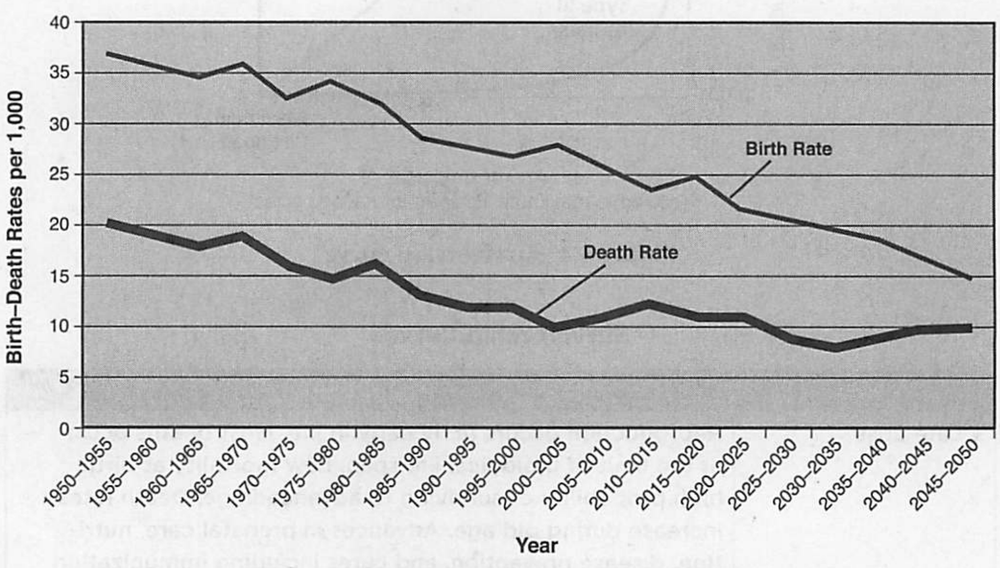


Figure 6.5 Global birth and death rates (1950–2050)

The human population has had three surges in growth. These surges in population have been attributed to three factors: The first was the use of tools and fire. The second was the agricultural revolution, when humans stopped being hunter-gatherers and began to raise crops. The third was the industrial and medical revolutions within the last 200 years.

Human Population Growth

Time Period	Description	Practicing Worldview
Before Agricultural Revolution	~1 million to 3 million humans. Hunter-gatherer lifestyle.	Earth Wisdom—Natural cycles that can serve as a model for human behavior.
8000 B.C.E. to 5000 B.C.E.	~50 million humans. Increases due to advances in agriculture, domestication of animals, and the end of a nomadic lifestyle.	
5000 B.C.E. to 1 B.C.E.	~200 million humans. Rate of population growth during this period was about 0.03 to 0.05%, compared with today's growth rate of 1.3%.	Frontier Worldview—Viewed undeveloped land as a hostile wilderness to be cleared and planted, then exploited for its resources as quickly as possible.
0 C.E. to 1300 C.E.	~500 million humans. Population rate increased during the Middle Ages because new habitats were discovered. Factors that reduced population growth rate during this time were famines, wars, and disease (density-dependent factors).	
1300 C.E. to 1650 C.E.	~600 million humans. Plagues reduced population growth rate. Up to 25% mortality rates are attributed to the plagues that reached their peak in the mid-1600s.	
1650 C.E. to present	Currently ~6 billion humans. In 1650 C.E., the growth rate was ~0.1%. Today it is ~1.3%. Health care, health insurance, vaccines, medical cures, preventative care, advanced drugs and antibiotics, improvements in hygiene and sanitation, advances in agriculture and distribution, and education are factors that have increased the growth rate.	Planetary Management—Beliefs that as the planet's most important species, we are in charge of Earth; we will not run out of resources because of our ability to develop and find new ones; the potential for economic growth is essentially unlimited; and our success depends on how well we manage Earth's life-support systems mostly for our own benefit.
Present to 2050 C.E.	Estimates are as high as ~15 billion.	Earth Wisdom—Beliefs that nature exists for all Earth's species and we are not in charge of Earth; resources are limited and should not be wasted. We should encourage Earth-sustaining forms of economic growth and discourage Earth-degrading forms of economic growth; and our success depends on learning how Earth sustains itself and integrating such lessons from nature into the ways we think and act.

Distribution

In 1800, the vast majority of the world's population (65%) resided in Asia and Europe. By 1900, 25% of the human population lived in Europe largely due to the Industrial Revolution. Between 2000 and 2030, most of the growth will occur in the developing countries in Africa, Asia, and Latin America whose growth rates are much higher than those in more-developed countries. The more-developed countries in Europe and North America will have growth rates less than 1%. Some countries, such as Russia, Germany, Italy, and Japan, will even experience negative growth rates.

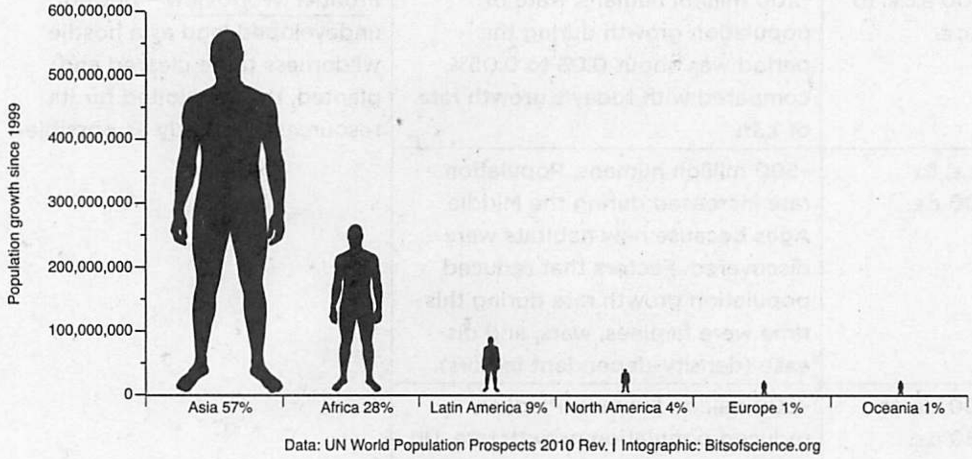


Figure 6.6 Distribution of the last billion people on Earth

Fertility Rates

Replacement level fertility (RLF) is the level of fertility at which a couple has only enough children to replace themselves, or about 2 children per couple. It takes a RLF of 2.1 to replace each generation since some children will die before they grow up to have their own two children. RLF rates are lower in moderately developed countries (MDC) and higher in developing countries due to higher infant mortality rates. Infant mortality rates are good indicators of comparative standards of living. The total fertility rate (TFR) is the average number of children that each woman will have during her lifetime. The country of Niger in Africa leads the world's TFR at 7.68.

Worldwide Total Fertility Rate

Country	TFR
Niger	7.68
India	2.65
Israel	2.72
Mexico	2.31
United States	2.06
China	1.54
Russia	1.54
Japan	1.21
World average	2.59

The two main effects of TFRs less than 2.1 without additions through immigration are population decline and population aging. The greatest TFR occurred during the post-World War II years (baby boomers). New immigrants and their descendants are projected to contribute 66% of the expected growth by 2050.

Despite half of the world's population having subreplacement fertility rates, the world's population is still growing quickly. This growth is due to nations with above-replacement TFRs and a population momentum caused by large numbers of younger females who have not had children as of yet.

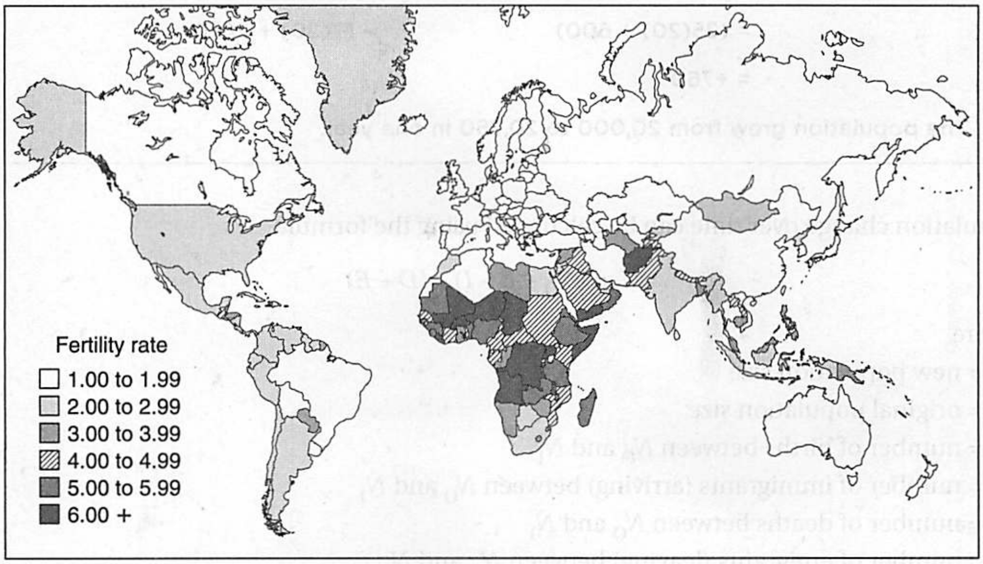


Figure 6.7 Worldwide total fertility rates

Declines in fertility rates can be attributed to several factors:

- Urbanization results in a higher cost of living and reduces the need for extra children to work on farms.
- There is a greater personal acceptance and government encouragement of contraception.
- The number of females in the workforce has increased.
- Female educational opportunities are increasing.
- More individuals desire to increase their standard of living by having less children.
- Many "millennials" are postponing marriage until their careers are established.
- As developing countries transition to developed countries, there is greater access to primary health care and family planning services.

BIRTH AND DEATH RATE CALCULATIONS

The birth rate, or crude birth rate, is equal to the number of live births per 1,000 members of the population in one year. The death rate, or crude death rate, is equal to the number of deaths per 1,000 members of the population in one year.

Immigration refers to the number of individuals that enter the population, while emigration refers to the number of individuals that leave the population. Population change can be calculated using the following formula:

Population change = (crude birth rate + immigration) – (crude death rate + emigration)

EXAMPLE

In 1950, the population of a small suburb in Los Angeles, California, was 20,000. The birth rate was measured at 25 per 1,000 population per year, while the death rate was measured at 7 per 1,000 population per year. Immigration was measured at 600 per year, while emigration was measured at 200 per year. By how much did the population increase (or decrease) in that year?

Answer:

Population change = (crude birth rate + immigration) – (crude death rate + emigration)

= (25(20) + 600) – (7(20) + 200)

= +760

The population grew from 20,000 to 20,760 in one year.

Population change over time can be calculated using the formula

$$N_1 = (N_0 + B + I) - (D + E)$$

where

N_1 = new population size

N_0 = original population size

B = number of births between N_0 and N_1

I = number of immigrants (arriving) between N_0 and N_1

D = number of deaths between N_0 and N_1

E = number of emigrants (leaving) between N_0 and N_1

EXAMPLE

A small city in Ohio had a population of 1,000 in 1920. Over the next 10 years, there were 100 births, 50 deaths, 200 people who left the city, and 600 people who arrived. What was the population of this city in 1930?

Answer:

$$N_1 = (N_0 + B + I) - (D + E)$$
$$= (1{,}000 + 100 + 600) - (50 + 200)$$
$$= 1{,}450$$

The actual rate of population change can be determined by using the following formula:

$$\text{Actual growth rate (\%)} = \frac{\text{birth rate} - \text{death rate}}{10}$$

EXAMPLE

The United States had a birth rate of 14.6 live births per 1,000 population in one year, compared to India's birth rate of 22.2 in that same year. The death rate in that year for the United States was 8.3 deaths per 1,000 population, compared to India's rate of 6.4. Calculate the population growth rates (%) for both the United States and India for that year.

Answer:

$$\text{United States: } \frac{\text{birth rate - death rate}}{10} = \frac{14.6-8.3}{10} = 0.6$$

$$\text{India: } \frac{\text{birth rate - death rate}}{10} = \frac{22.2-6.4}{10} = 1.6$$

A current world growth rate of approximately 1.3% when applied to the about 7 billion people on Earth yields an annual increase of about 85 million people. Because of the large and increasing population size, the number of people added to the global population will remain high for several decades, even if growth rates decline.

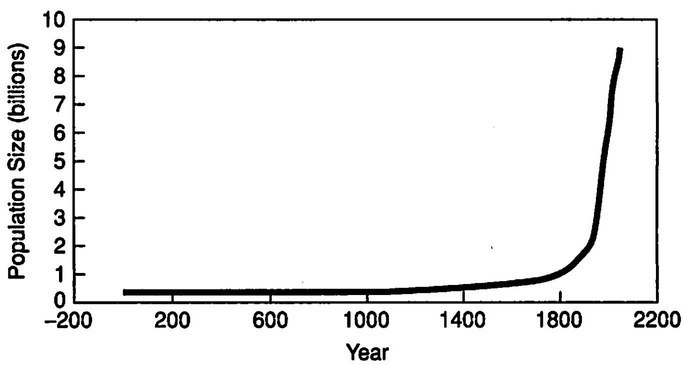


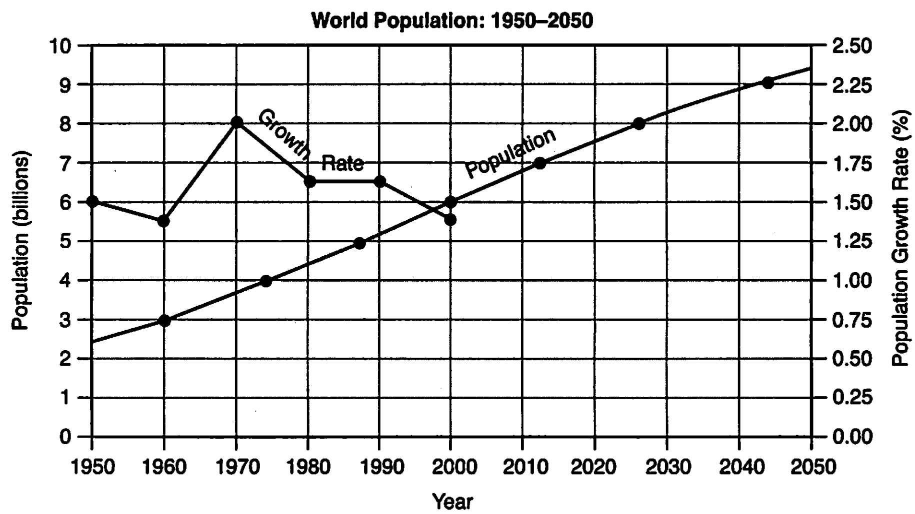
Figure 6.8 Estimated human population growth from 200 B.C.E. to 2200 C.E.

Growth Rates and Doubling Times

The 20th century saw the largest increase in the world's population in human history. The following chart shows the doubling times of the world's population:

Year Span	Number of Years to Double
950 C.E. to 1600	650 years
1600 to 1800	200 years
1800 to 1925	125 years
1925 to 1975	50 years
1975 to 2025	50 years

Note that the doubling times from 1925 to 1975 and projected from 1975 to 2025 remain constant. This does NOT mean that the world is not increasing in population—it means that the growth *rate* has decreased as shown in the following figure.



Source: U.S. Census Bureau, International Data Base, December 2010 Update

Figure 6.9 Yearly growth rate of the human population (1950–2050)

RULE OF 70

The Rule of 70 is a useful rule of thumb that roughly explains the time periods involved in exponential growth at a constant rate. Doubling time is the amount of time it takes for a given quantity to double in size or value at a constant growth rate. We can find the doubling time for a population undergoing exponential growth by using the Rule of 70, where *dt* represents the change in time, and *r* represents the growth rate, which must be entered as a whole number and not as a decimal (e.g., 2% = 2).

$$dt = \frac{70}{r}$$

For example, a population with a 2% annual growth rate would have a doubling time of 35 years.

$$35 = \frac{70}{2}$$

Key properties of doubling time are:

- The larger the growth rate, (r), the faster the doubling time.
- The growth rate varies considerably among organisms (e.g., most small-bodied organisms grow faster and have larger rates of population increase than larger organisms [i.e., bacteria vs. elephants]).
- Populations cannot double forever. Resistance factors, like natural resource constraints and disease, contribute to a leveling off in population size over time once the carrying capacity is reached (i.e., logistic growth).

DEMOGRAPHIC TRANSITION

Demographic transition is the name given to the process that has occurred during the past century. It leads to a stabilization of population growth in the more highly-developed countries and is generally characterized as having four separate stages: pre-industrial, transitional, industrial, and post-industrial.

Stage 1: Pre-Industrial

Living conditions are severe, medical care is poor or nonexistent, and the food supply is limited due to poor agricultural techniques, preservation, and pestilence. Birth rates are high to replace individuals lost through high mortality rates. The net result is little population growth. Many countries in sub-Saharan Africa have reverted back to this stage due to the increase of AIDS.

Stage 2: Transitional

This stage occurs after the start of industrialization. Standards of hygiene, advances in medical care, improved sanitation, cleaner water supplies, vaccinations, and higher levels of education begin to drive down the death rate, leading to a significant upward trend in population size. The net result is a rapid increase in population. Examples include India, Pakistan, and Mexico.

Stage 3: Industrial

Urbanization decreases the economic incentives for large families. The cost of supporting an urban family grows, and parents are more actively discouraged from having large families. Educational and work opportunities for women decrease birth rates. Obtaining food is not a major focus of the day, and leisure time is available. Retirement safety nets are in place, reducing the need for extra children to support parents. In response to these economic pressures, the birth rate starts to drop, ultimately coming close to the death rate (e.g., China).

Stage 4: Post-Industrial

Birth rates equal mortality rates, and zero population growth is achieved. Birth and death rates are both relatively low, and the standard of living is much higher than during the earlier periods. In some countries, birth rates may actually fall below mortality rates and result in net losses in population. Examples of declining populations include Russia, Japan, and many European countries. The developed world currently remains in this fourth stage of demographic transition.

Stage 5: Sub-Replacement Fertility

The original demographic transition model has just four stages; however, some theorists consider that a fifth stage is needed to represent countries that have sub-replacement fertility (that is, below 2.1 children per woman). Most European and many East Asian countries now have higher death rates than birth rates. In this stage, population aging and population decline will eventually occur to some extent, presuming that sustained mass immigration does not occur.

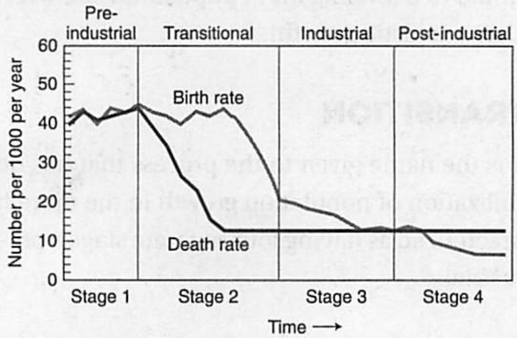


Figure 6.10 Demographic transitions occurring in human populations

AGE-STRUCTURE DIAGRAMS

A good indicator of future trends in population growth is furnished by age-structure diagrams. Age-structure diagrams are determined by birth rate, generation time, death rate, and sex ratios. There are three major age groups in a population: pre-reproductive, reproductive, and post-reproductive. A pyramid-shaped age-structure diagram (e.g., Nigeria) indicates that the population has high birth rates and the majority of the population is in the reproductive age group (generally late teens to mid-40s). A bell-shape indicates that pre-reproductive and reproductive age groups are more nearly equal, with the post-reproductive group being smallest due to mortality; this is characteristic of stable populations (i.e., United States). An urn-shaped diagram indicates that the post-reproductive group is largest and the pre-reproductive group is smallest, a result of the birth rate falling below the death rate, and is characteristic of declining populations (e.g., Germany).

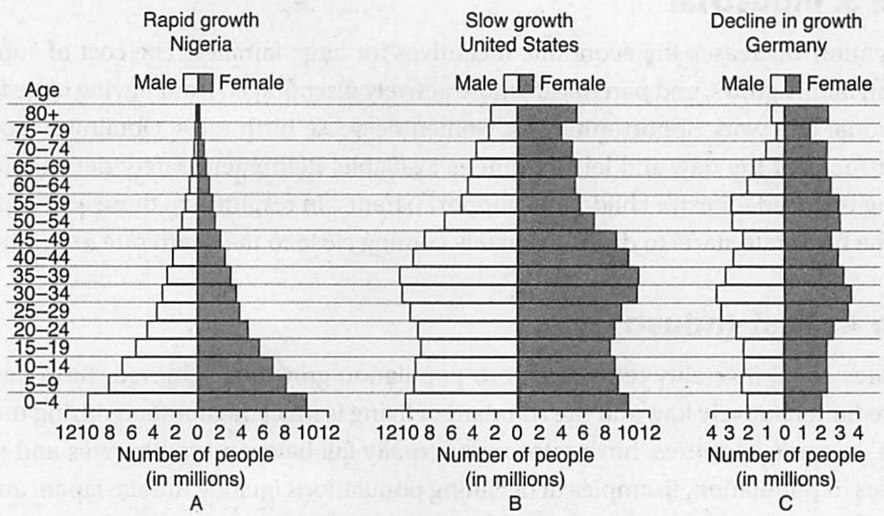
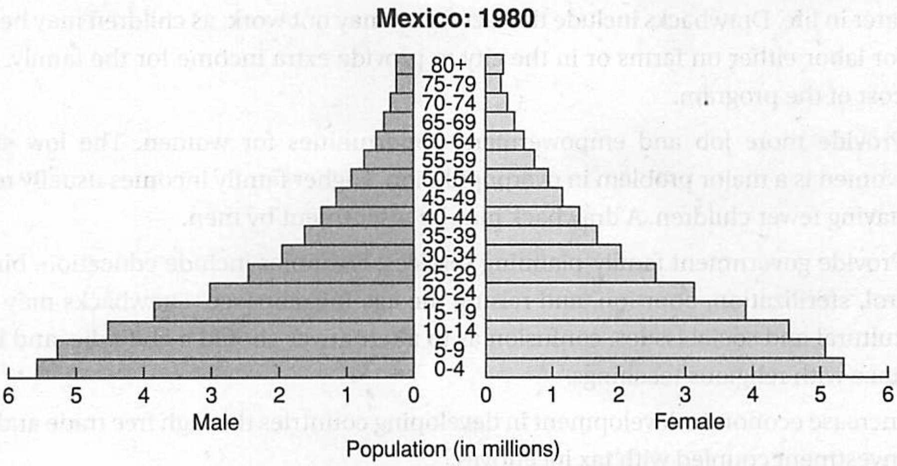


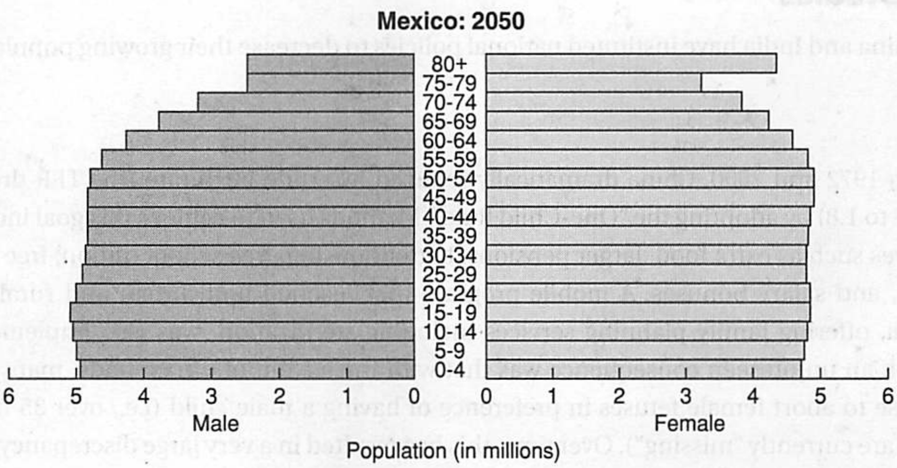
Figure 6.11 Age-structure diagrams for countries with rapid, slow, and declining birth rates

The age-structure diagrams in the figure below show age distributions of developing countries compared with more-developed countries. When the base is large (greater number of younger individuals in the population), there is a potential for an increase in the population as these younger individuals mature and have children of their own (population momentum). When the top of the pyramid is larger, it indicates a large segment of the population is past their reproductive years (post-reproductive) and indicates a future slowdown in population growth. Age-structure diagrams reflect demographic transitions.

In Mexico, large family size is due to the necessity for farm labor, the need to support parents when they no longer work, a need to increase family income, and cultural and religious beliefs. The death rate has declined due to social and medical programs. However, the birth rate continues to remain high.



Source: U.S. Census Bureau, International Data Base



Source: U.S. Census Bureau, International Data Base

Figure 6.12 Age-structure diagrams for Mexico, 1980 and 2050 (estimated)

POPULATION SIZE

This section discusses several strategies to sustain population size and then provides a few Case Studies.

Strategies for Population Sustainability

- Provide economic incentives for having fewer children. Possible drawbacks would be that rewards may be given to people who already have the number of children they want and the cost of the program.
- Provide free education, housing subsidies, monthly subsidies, free health care, higher pension benefits, tax incentives, or other economic incentives to women who only have one or two children. Higher education for women usually results in having children later in life. Drawbacks include the fact that it may not work, as children may be needed for labor either on farms or in the city to provide extra income for the family, and the cost of the program.
- Provide more job and empowerment opportunities for women. The low status of women is a major problem in overpopulation. Higher family incomes usually results in having fewer children. A drawback may be resentment by men.
- Provide government family-planning services. Examples include education, birth control, sterilization, abortion, and raising the age for marriage. Drawbacks may include cultural and social issues, confusion as to alternatives should a child die, and interference with religious teachings.
- Increase economic development in developing countries through free trade and private investment coupled with tax incentives.
- Improve prenatal and infant health care. Women would not need to have more children if the ones they had survived.

Case Studies

Both China and India have instituted national policies to decrease their growing populations.

CHINA

Between 1972 and 2000, China dramatically reduced its crude birth rate (the TFR dropped from 5.7 to 1.8) by adopting the "One-Child Rule." Methods used to achieve this goal included incentives such as extra food, larger pensions, better housing, free school tuition, free medical care, and salary bonuses. A mobile program that reached both urban and rural areas of China, offering family planning services including sterilization, was also implemented. However, an unforeseen consequence was that with the advent of ultrasounds, many families chose to abort female fetuses in preference of having a male child (i.e., over 35 million females are currently "missing"). Over time, this has resulted in a very large discrepancy in the male to female ratio in China (i.e., 130 males for every 100 females).

In 2016, in response to an aging population and the large discrepancy in the sex ratio, China adopted a "Two-Child Rule."

INDIA

In 1952, India (with a population of 400 million at the time) began its first family planning program. In 2000, India's population was 1 billion, or 16% of the world's population. Each day there are 50,000 live births in India. One-third of the population of India earns less than 40 cents per day, and cropland has decreased 50% per capita since 1960. In the 1970s, India instituted a mandatory sterilization program involving vasectomies. Some of the reasons for India's family planning failures were poor planning, low status of women, favoring male children, and insensitivity to cultures and religion. Tubal ligation is the preferred method of family planning in India today. Condoms are free from the Indian government but have less than 10% use. Other birth control methods are usually accepted by only the upper/educated class.

GENDER BIAS—SEX SELECTION

Male child preference is manifest in sex-selective abortions, based on the results of sonograms, and in the discrimination in health care practices for girls, both of which lead to higher female mortality. Based on a 50/50 male-to-female population birth ratio, it is estimated that there are more than 100 million "missing girls" across the developing world. Although improved health care and conditions for women have resulted in reductions in female mortality, these advances are offset by an increase in the use of sex-selective abortions. Largely as a result of this practice, there are now an estimated 80 million missing females in India and China alone.

Measures to reduce sex selection include strict enforcement of existing legislation, the guarantee of equal rights for women, and public awareness campaigns about the dangers of gender imbalance.

IMPACTS OF POPULATION GROWTH

- **BIODIVERSITY:** The Earth's biological diversity is crucial to the continued vitality of agriculture and medicine. Yet, human activities are pushing many thousands of plant and animal species into extinction with two-thirds of the world's species in decline.
- **COASTLINES AND OCEANS:** Half of all coastal ecosystems are pressured by high population densities and urban development. Ocean fisheries are being overexploited, estuaries (nurseries of the sea) are being drained and filled in because of population growth, and fish catches are down.
- **FORESTS:** Nearly half of the world's original forest cover has been lost, and each year another 16 million hectares are cut, bulldozed, or burned. Forests provide over $400 billion to the world economy annually and are vital to maintaining healthy ecosystems. Yet, the current demand for forest products may exceed the limit of sustainable consumption by 25%.
- **FOOD SUPPLY AND MALNUTRITION:** Today, one-quarter of the world's population is malnourished. In 64 of 105 developing countries, most notably in Africa, Asia, and parts of Latin America, the population has been growing faster than available food supplies. Population pressures have also degraded some 2 billion hectares of arable land—an area the size of Canada and the United States combined.

  The issue is not that the world does not produce enough food. The issue is that too many people cannot afford food and that it is not distributed equally. If all food grown and raised on Earth was distributed equally, it would result in 4.3 pounds (2 kg) of food per person per day. Advances made during the first and second green revolutions, which focused on increasing food production, have not ended world famine and malnutrition. Even though poorer countries (e.g., India, the Philippines, and many African countries) have been able to increase their food production through technological improvements, the food production (often by large, foreign, multinational corporations whose motivation is profit) is often sold to other wealthier countries that are able to pay higher prices.

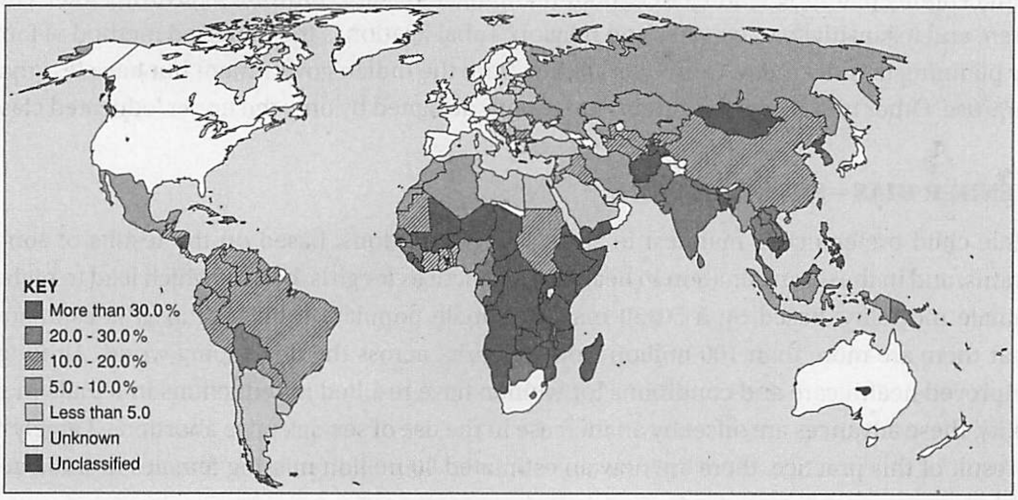


Figure 6.13 Worldwide malnutrition

- **FRESHWATER:** The supply of freshwater is finite, but demand is soaring as the population grows and per capita use rises.
- **GLOBAL CLIMATE CHANGE:** Earth's surface is warming due to greenhouse gas emissions, largely from burning fossil fuels. If the global temperature rises as projected, sea levels would rise by several meters, causing widespread flooding, with global warming projected to cause droughts and disrupt agriculture.
- **PUBLIC HEALTH AND INCREASE IN DISEASE:** Unclean water, along with poor sanitation, kills over 12 million people each year, most in developing countries. Air pollution kills nearly 3 million more. Heavy metals and other contaminants also cause widespread health problems.

  The World Health Organization estimates that, by 2020, tobacco-related illnesses, including heart disease, cancer, and respiratory disorders, will be the world's leading cause of death and will be responsible for more deaths than AIDS, tuberculosis, road accidents, murder, and suicide combined. In 2017, the economic cost of smoking tobacco was more than $300 billion, which included $170 billion in direct medical care and more than $156 billion in lost productivity due to premature death and exposure to secondhand smoke.
- **UNEQUAL DISTRIBUTION OF WEALTH AND GOVERNMENTAL PRIORITIES:** Rapid population growth rates can make it politically difficult for countries to raise standards of living and, at the same time, protect the environment because of governmental priorities, financial restraints, and special interest groups (e.g., spending money on food, health care, education, housing, jobs, energy, etc. vs. spending that same money on wetland restoration). Adding more people to a country's population means that the wealth must be redistributed among more people, causing the gross domestic product (GDP) per capita to decrease.

CASE STUDY

HIV/AIDS (1983–PRESENT): The HIV/AIDS pandemic* has had a considerable and dramatic impact on mortality rates, life expectancy, and population growth rates, especially in sub-Saharan Africa. A change in life expectancy at birth, defining the average number of years a newborn is expected to live, is one of the most direct indicators for development and indicates the progress a country has made in improving the standard of living in terms of factors such as income, health, and education, resulting in longer lives for its population. Current trends show that by killing and incapacitating adults in the prime of their lives, HIV/AIDS undercuts human security and derails development, leading to a dramatic decline in the life expectancy of affected countries. The high incidence of HIV infection within the age group of 15 to 24 years means that the majority die before they reach their thirties, resulting in lower total fertility rates. However, the development and distribution of antiretroviral drugs is beginning to have an impact on mortality rates in areas where these drugs are available and affordable.

An epidemic occurs when the incidence rate of a certain disease outbreak is concentrated in a particular region and substantially exceeds what is expected. A pandemic is an epidemic of an infectious disease that spreads through human populations across a wide geographic area (continents) and affects a very high proportion of the human population.

MULTIPLE-CHOICE QUESTIONS

1. Which would be least likely to be affected by a density-dependent limiting factor?

   (A) A small, scattered population
   (B) A population with a high birth rate
   (C) A large, dense population
   (D) A population with a high immigration rate
   (E) None of the above

2. A population showing a growth rate of 20, 40, 60, 80, . . . would be characteristic of

   (A) logarithmic growth
   (B) exponential growth
   (C) static growth
   (D) arithmetic (linear) growth
   (E) power curve growth

3. If a population doubles in about 70 years, it is showing a ______ % growth rate.

   (A) 1
   (B) 5
   (C) 35
   (D) 140
   (E) 200

4. An island off Costa Rica includes 500 birds of a particular species. Population biologists determined that this bird population was isolated with no immigration or emigration. After one year, the scientists were able to count 60 births and 10 deaths. The net growth for this population was

   (A) 0.5
   (B) 0.9
   (C) 1.0
   (D) 1.1
   (E) 1.5

5. Afghanistan has a current growth rate of 4.8%, representing a doubling time of approximately

   (A) 4.8 years
   (B) 9.6 years
   (C) 14.5 years
   (D) 35 years
   (E) 70 years

6. Biotic potential refers to
   (A) an estimate of the maximum capacity of living things to survive and reproduce under optimal environmental conditions
   (B) the proportion of the population of each sex at each age category
   (C) the ratio of total live births to total population
   (D) a factor that influences population growth and that increases in magnitude with an increase in the size or density of the population
   (E) events and phenomena of nature that act to keep population sizes stable

7. The number of children an average woman would have, assuming that she lives her full reproductive lifetime, is known as the
   (A) birth rate
   (B) crude birth rate
   (C) TFR
   (D) RLF
   (E) zero population growth rate

8. The average American's ecological footprint is approximately
   (A) the size of a shoe
   (B) 0.5 acres
   (C) 3 acres
   (D) 6 acres
   (E) 12 acres

9. Which of the following statements is FALSE?
   (A) The United States, while having only 5% of the world's population, consumes 25% of the world's resources.
   (B) Up to 50% of all plants and animals could become extinct within the next 100 years.
   (C) In 1990, 20% of the world's population controlled 80% of the world's wealth.
   (D) Every second, five people are born and two people die, a net gain of three people.
   (E) They are all true statements.

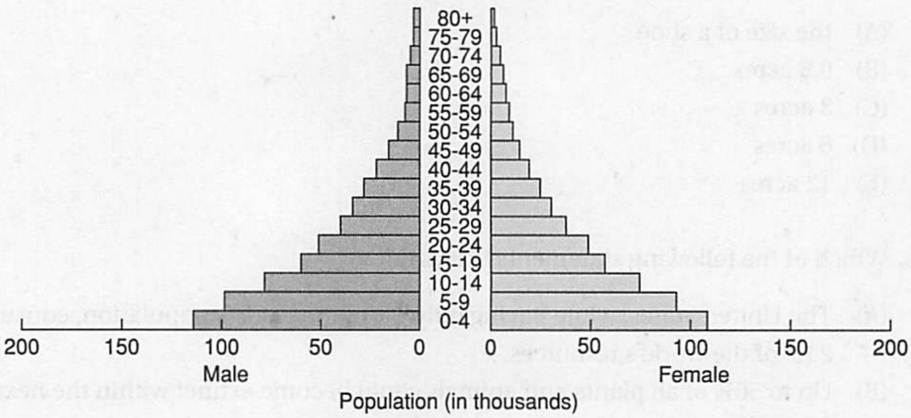
10. Pronatalists (people in favor of having many children) would agree with all of the following arguments EXCEPT

    (A) many children die early due to health and environmental conditions
    (B) children are expensive and time intensive
    (C) children provide extra income for families
    (D) children provide security for parents when the parents reach old age
    (E) status of the family is often determined by the number of children

11. The number one cause of death worldwide is

    (A) cancer
    (B) heart disease
    (C) AIDS
    (D) stroke
    (E) lower respiratory diseases (flu, pneumonia, and tuberculosis combined)

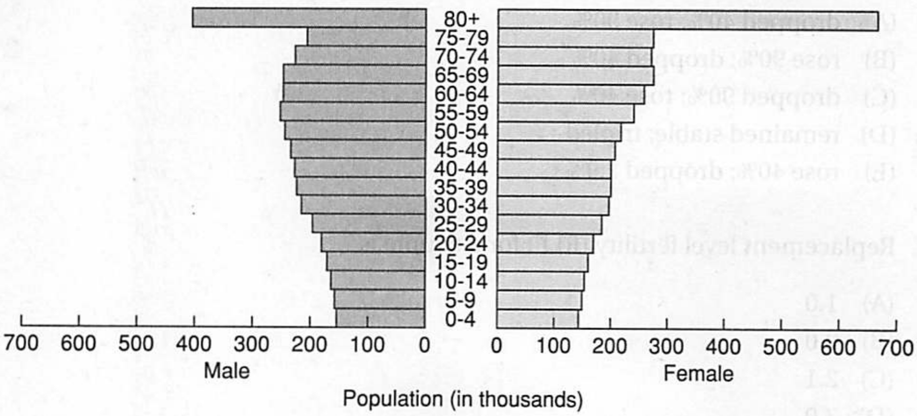
12. The following age-structure diagram would be typical of



Source: U.S. Census Bureau, International Data Base

    (A) Russia
    (B) China
    (C) the United States
    (D) Ethiopia or Peru
    (E) Canada

13. Examine the following age-structure diagram.



Source: U.S. Census Bureau, International Data Base

This population will be

(A) declining rapidly in the future
(B) growing slowly in the future
(C) remaining stable
(D) growing rapidly in the future
(E) declining slowly in the future

14. Which of the following examples does NOT demonstrate a density-dependent factor affecting the population size?

(A) The "black plagues" that occurred in Europe during the mid 14th century and which are estimated to have killed up to one-third of the European population
(B) The number of lions inhabiting a grassland in Africa
(C) Tropical plants located near the ground in a tropical rainforest
(D) An outbreak of influenza in a hospital
(E) The destruction of a rainforest in Brazil due to drought

15. Density-independent factors would include all of the following EXCEPT

(A) drought
(B) fires
(C) predation
(D) flooding
(E) All of the above are density-dependent.

16. Between 1963 and 2000, the rate of the world's annual population change _____ but the human population size _____.

(A) dropped 40%; rose 90%
(B) rose 90%; dropped 40%
(C) dropped 90%; rose 40%
(D) remained stable; tripled
(E) rose 40%; dropped 2.9%

17. Replacement level fertility (RLF) for a couple is

(A) 1.0
(B) 2.0
(C) 2.1
(D) 3.0
(E) varies depending on country

18. Which of the following factors is associated with the highest potential for population growth?

(A) High percentage of people under age 18
(B) High percentage of people in their 30s
(C) High percentage of people in their 50s
(D) High percentage of people in high-income groups
(E) High percentage of people in low-income groups

19. Using the demographic transition model, what stage would be characteristic of death rates falling while birth rates remain high?

(A) Pre-industrial
(B) Industrial
(C) Post-industrial
(D) Transitional
(E) None of the above

20. All of the following factors tend to cause women to have fewer children EXCEPT

(A) higher education
(B) high infant mortality
(C) better prenatal care
(D) birth control education
(E) human rights are protected

FREE-RESPONSE QUESTION

Gold was discovered in 1848 in the foothills of the Sierra Nevada mountain range in California. The fictional town of Barronsville soon sprang up serving the needs of the miners and others who flocked to the area. Below is a chart of several population parameters of Barronsville from 1850 through 1890.

Year	Total Number of Immigrants During Last 10 Years	Total Number of Emigrants During Last 10 Years	Total Number of Births During Last 10 Years	Total Number of Deaths During Last 10 Years	Population
1850	500	0	0	0	500
1860	2,480	0	50	30	3,000
1870	500	?	30	40	1,450
1880	10	1,000	?	7	620
1890	0	200	0	2	?

(a) Calculate the following. Show all work.

(i) The number of emigrants between 1860 and 1870.

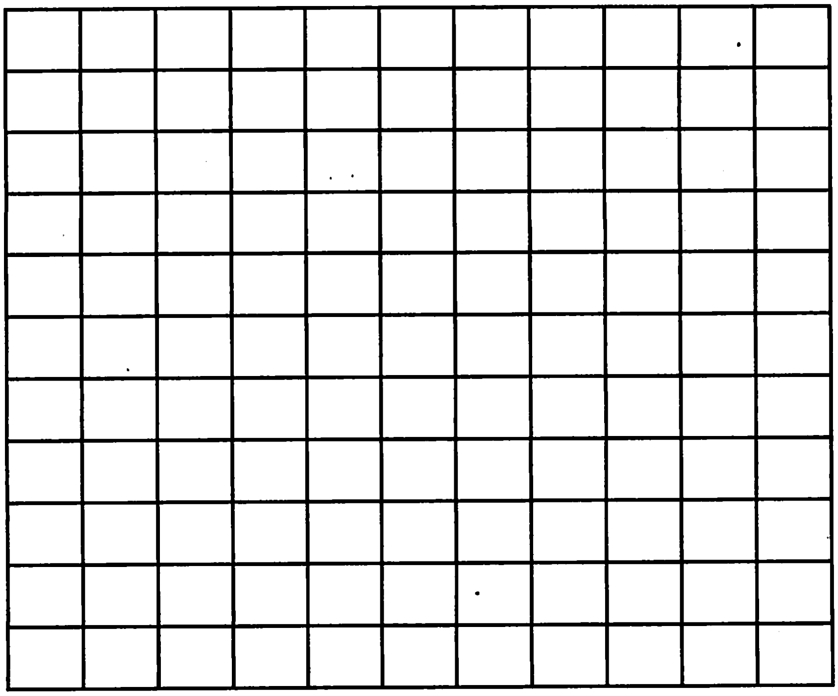
(ii) The number of births between 1870 and 1880.

(iii) The population in 1890.

(b) The following chart shows the number of births and deaths in Barronsville from 1850 through 1859.

Year	Births/1,000	Deaths/1,000	Population
1850	0	0	500
1851	0	0	600
1852	0	0	700
1853	0	1.25	800
1854	1.11	1.11	900
1855	2.00	1.00	1,000
1856	3.84	1.54	1,300
1857	4.00	1.71	1,750
1858	6.36	3.18	2,200
1859	7.90	5.66	2,650

On the graph below, plot the crude birth rate and the crude death rate for Barronsville between 1850 and 1859. Clearly label the axes and the curves.



(c) Indicate TWO factors that may have accounted for the rapid decline in the population in Barronsville between 1850 and 1890.

(d) Cyanide and mercury are toxic pollutants that are still used in gold mining today. Choose ONE of these chemicals and explain how they are used in gold mining and their effect on the environment and human health.

MULTIPLE-CHOICE ANSWERS AND EXPLANATIONS

1. **(A)** Increasing population size reduces available resources, thus limiting population growth. In restricting population growth, a density-dependent factor intensifies as the population size increases, affecting each individual more strongly. Population growth declines because of death rate increase, birth rate decrease, or both. There is a reduction in the food supply, which restricts reproduction resulting in less offspring. The competition for space to establish territories is a behavioral mechanism that may restrict population growth. Predators concentrate in areas where there is a high concentration of prey. As long as the natural resources are available in sufficient quantity, the population will remain constant. As the population decreases, so do predators. The accumulation of toxic wastes may also limit the size of a population. Intrinsic factors may play a role in limiting a population size. High densities may cause stress syndromes, resulting in hormonal changes that may delay the onset of reproduction. It has also been reported that immune disorders are related to stress in high densely populated areas. Density-independent factors include weather, climate, and natural disasters such as freezes, seasonal changes, hurricanes, and fires. These factors affect all individuals in the population, regardless of population size.
2. **(D)** Arithmetic or linear growth is characterized by a constant increase per unit of time. In this case, the constant is an increase of 20.
3. **(A)** A 1% growth rate would cause a population to double in 70 years. Hint: divide 70 by the annual percentage growth rate to get the doubling time in years.
4. **(D)** Population size = original size (500) + births (60) – deaths (10) + immigration (0) – emigration (0) = 550. Net growth *rate* = 550/500 = 1.1.
5. **(C)** Using the Rule of 70, 70/4.8 = 14.5 years.
6. **(A)** The maximum reproductive rate is called the biotic potential.
7. **(C)** Global TFR is approximately 2.6.
8. **(E)** An ecological footprint is a metaphor used to depict the amount of land a person would hypothetically need to provide the resources required to support himself.
9. **(E)** These are, in fact, all true statements.
10. **(B)** Pronatalists urge people to have many children. Choice (B) is the only argument provided that does not promote having children.
11. **(B)** According to the World Health Organization (WHO), heart disease killed 7 million people worldwide in 2011 and is currently the number one cause of death worldwide. Contributory factors to heart disease include a poor diet, lack of exercise, being overweight, high alcohol intake, and smoking. Leading causes of death following heart disease (in order) are: stroke, lower respiratory infection (includes pneumonia, flu, and tuberculosis), pulmonary disease (includes asthma, emphysema, and bronchitis), diarrheal diseases (mostly in children), HIV-AIDS, respiratory cancer (lung, tracheal, and bronchial), diabetes, traffic accidents (3,500 daily), and prematurity.
12. **(D)** Age-structure diagrams with a wide base are populations that have a high proportion of young people, which results in a powerful, built-in momentum to increase population size, assuming death rates do not unexpectedly increase.

13. **(A)** This graph is the reverse of the diagram in Question 12. In this case, the majority of the population is beyond reproductive years, and the death rate exceeds the birth rate. This projected age-structure diagram is for Hong Kong in 2050.

14. **(E)** Choices A–D are examples of density-dependent factors, wherein large, dense populations are more strongly affected than small, less crowded ones. Drought is a naturally occurring event and does not depend on the density of any organism(s) occurring in the area. However, had the destruction of the rainforest been due to ranching, timber harvesting, and/or agriculture (as is the most common cause), then an increase in the number of humans in the rainforest would increase the amount of rainforest destruction, in which case the destruction would be due to density-dependent elements.

15. **(C)** Density-independent factors influence population growth and do not depend on the size or density of the population. Predation rates are affected by population size.

16. **(A)** The population growth rate measures how fast the size of population is changing over time. Population size is the total number of individuals.

17. **(C)** A TFR of 2.1 is considered the replacement rate. Once the TFR of a population reaches 2.1, the population will remain stable, assuming no immigration or emigration takes place.

18. **(A)** Population momentum is the tendency for changes in population growth rates to lag behind changes in childbearing behavior and mortality conditions. Momentum operates through the population age distribution. A population that has been growing rapidly for a long time acquires a "young" age distribution that will result in positive population growth rates for many decades into the future.

19. **(D)** In the pre-industrial stage, living conditions are harsh, birth and death rates are high, and there is little increase in population size. In the transitional stage, living conditions improve, the death rate drops, and birth rates remain high. In the industrial stage, growth slows. In the post-industrial stage, zero population growth is reached, and the birth rate falls below the death rate.

20. **(B)** Countries with high infant mortality rates generally have high TFRs.

FREE-RESPONSE ANSWER

10 Total Points Possible

(a) Maximum 3 points total, 1 point maximum for each correct answer. Must show work.

(i) *The number of emigrants between 1860 and 1870. (1 point maximum)*

$$N_{1870} = (N_{1860} + B + I) - (D + E) \text{ where}$$

$$1{,}450 = (3{,}000 + 30 + 500) - (40 + E)$$

$$E = 2{,}040$$

(ii) *The number of births between 1870 and 1880. (1 point maximum)*

$$N_{1880} = (N_{1870} + B + I) - (D + E)$$

$$620 = (1{,}450 + B + 10) - (7 + 1{,}000)$$

$$B = 167$$

(iii) *The population in 1890. (1 point maximum)*

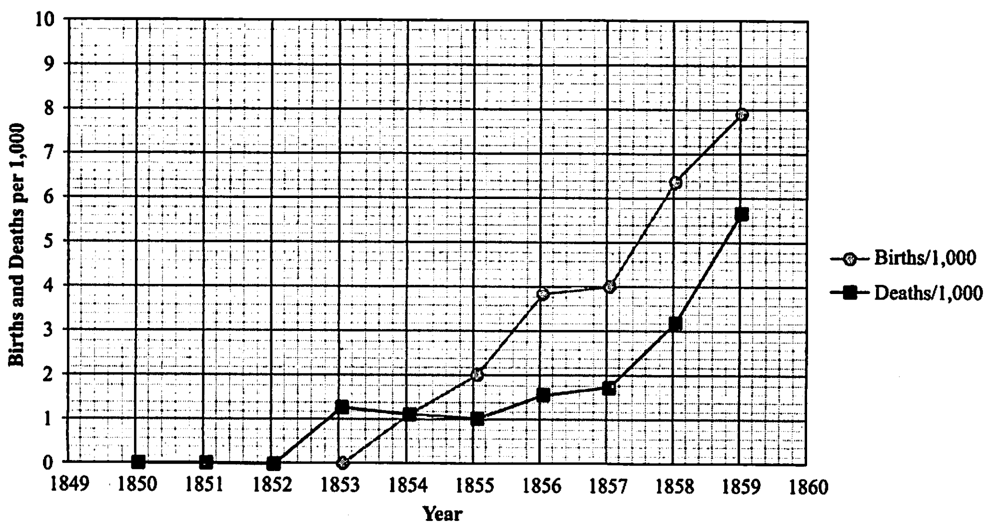
$$N_{1890} = (N_{1880} + B + I) - (D + E)$$

$$N_{1890} = (620 + 0 + 0) - (2 + 200)$$

$$N_{1890} = 418$$

(b) Maximum 3 points total.

Plot the crude birth rate and the crude death rate for Barronsville between 1850 and 1859. Clearly label the axes and the curves. (1 point maximum for correctly scaling and labeling the axes. Each axis must include all data between 1850 and 1859. 2 points for correctly plotting both rates.)



(c) Maximum 2 points total, 1 point for each factor described.

Identify TWO factors that may have accounted for the rapid decline in the population in Barronsville between 1850 and 1890. (1 point maximum for each possible cause for the population to decline. Only the first two factors provided are considered.)

Possible factors might include:

- What gold existed in the area was extracted to the point where it was not economical to mine anymore.
- Lack of proper sanitation and/or health care which could have created conditions for disease or an epidemic.
- News of a richer strike in another location.
- Pollution and health effects caused by chemicals used during the gold extraction process.

(d) *Maximum 2 points total.*

Cyanide and mercury are toxic pollutants that are still used in gold mining today. Choose ONE of these chemicals and explain how they are used in gold mining and their effect on the environment and human health. (1 point for a correct explanation of the process, and 1 point for a correct explanation of the health and/or environmental effect(s).)

After being brought to the surface, the ore must be processed to extract the mineral, which generates huge quantities of waste. The amount of recoverable metal in even high grade ores is generally just a small fraction of the total mass. Every ounce of gold produced results in 30 tons of mine waste. Gold is commonly extracted from the ore through a technique called "heap leaching." The ore containing the gold is crushed, piled into heaps, and sprayed with a solution containing cyanide, which trickles down through the ore and bonds with the gold. The resulting gold-cyanide solution is collected at the base of the heap and pumped to a mill, where the gold and cyanide are chemically separated. The cyanide is then stored in artificial ponds for reuse. Each bout of leaching takes a few months, after which the heaps receive a layer of fresh ore. Given the scale and duration of these operations, contamination of the surrounding environment with cyanide is almost inevitable. To dispose of the leftover ore (tailings) contaminated with cyanide and other toxins, a dam is constructed which allows percolation of these toxins into the groundwater. These dams are also often structurally unsound.

OR

Amalgamation is a commonly used gold extraction process that unleashes widespread mercury contamination and poisons local ecosystems. Mercury is first brought into contact with gold, resulting in a solution of gold in mercury called an amalgam. After the mercury has gathered in the gold it can be removed by dissolving it in nitric acid or by evaporating it with heat, leaving the gold behind. Vast quantities of mercury vapor are released into the environment during this process. Mercury vapor has serious health consequences for both animals and humans. The amount of mercury vapor released by mining activities has been proven to damage the kidneys, liver, brain, heart, lungs, colon, and immune system. Chronic exposure to mercury may result in fatigue, weight loss, tremors, and behavioral and personality shifts.