CHAPTER 11

Population Biology and Dynamics

IN THIS CHAPTER

Summary: By understanding the way populations are defined, how they grow, and what their needs are, scientists and policy makers can better plan for the sustainability of resources needed by a population and its ecosystem.

KEY IDEA

Keywords

✪ Population, ecosystem, exponential growth, carrying capacity, environmental resistance, *r*- and *K*-adapted species, immigration, emigration, mortality, life span, genetic drift

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Populations

In general, most people think of human populations when they hear the word population. However, to understand a population, you have to think in terms of groupings. A grouping of individuals of the same species located in the same geographical area is known as a *population.* This concept is applied to humans, prairie dogs, or sunflowers. Several populations of the same species in the same area are known as a *community.* When the environment is added into the overall equation, various populations and communities are considered an *ecosystem.* However, plant and animal species are constantly changing, moving, and dying off. These changes are part of the ecological succession described in Chapter 9.

TIP

Besides increasing birth rates or germination, populations also grow when organisms enter or *immigrate* into an ecosystem. In the case of seeds, they may be transported by birds or on the wind. Some animals may fly or swim into a new area, while others are hitchhikers on the fur or feathers of another species or carried in a ship's bilge water.

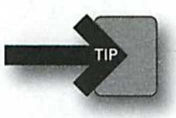
Internal Population Factors and Life Span

Lots of external factors affect populations. In fact, internal population factors are often controlled by changes in external factors. *Natality,* the germination, cloning, birth, or hatching of new individuals in a population, is affected by external factors (e.g., climate, temperature, moisture, and soil), which determine whether a population will grow or shrink.

Fecundity is the actual capability to reproduce, while *fertility* is a measure of the number of offspring produced. In animal populations, the fecundity of individuals determines a populations' fertility. However, in humans, if two people are physically capable (fecund), it is a matter of choice (with all the birth control options available) whether or not to reproduce.

At the other end of the reproductive spectrum, *mortality* or *death rate* is an internal factor increased or decreased by outside conditions such as extreme heat or cold. Mortality is calculated by dividing the number of individuals that die during a specific time period by the number alive at the start of the time period. Another way of looking at this is in terms of *survivorship,* which describes the number of individuals born at or near the same time, surviving to a specific age.

Life expectancy is the number of years a person is expected to live based on statistical probability. However, life expectancy for a specific person is not set. At birth, a person might be expected, statistically, to live to be 75 years old. However, since many people die at infancy and during childhood, a person who lives to be 74, and is still healthy, will most likely live 10 more years. Except for accidents, he or she will most likely exceed expectancy, rather than die the next year after beating the odds of early death.



Life span describes the longest interval of time a certain species is estimated to live. Life spans range from a matter of minutes to thousands of years. The maximum human life span is around 120 years. Figure 11.1 shows the four main life span types.

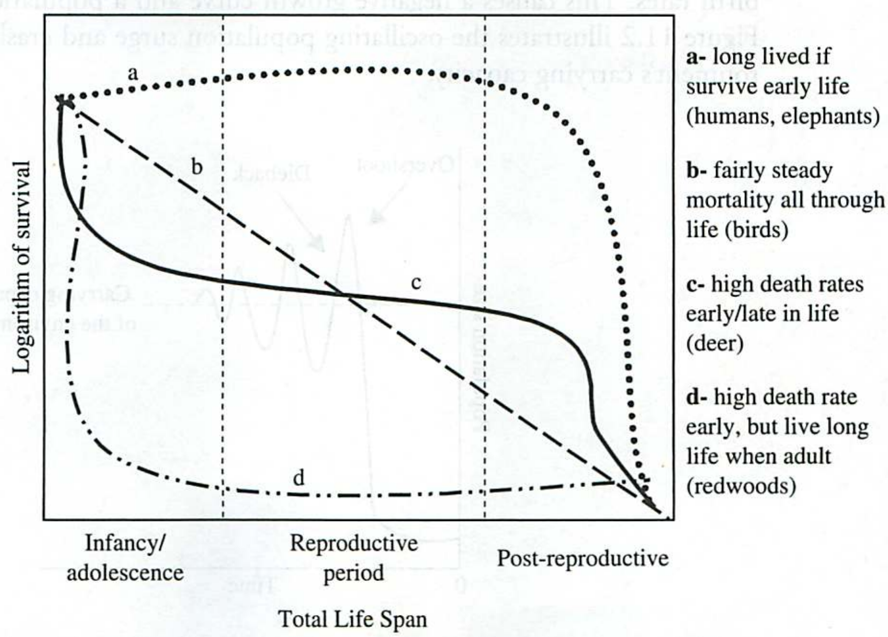


Figure 11.1 Different species have different types of life spans.

Exponential Growth

Sometimes populations experience a growth spurt, which is unrestricted for a time before lack of resources, space, or disease slows or stops it. This is known as *exponential growth.* The mathematical formula is written as the rate of growth (r) times the number of individuals (N), which is equal to the change in the number of individuals (ΔN) in a population over a change in time (Δt).

$$rN = \frac{\Delta N}{\Delta t}$$

The r component describes the average contribution of an individual to population growth. This equation finds a species' *biotic potential.*

STRATEGY

Researchers use a common math trick, called the rule of 70, to estimate population doubling. By dividing 70 by the annual percentage growth rate, you get a population's approximate *doubling time* in years. For example, if a population is growing at 20% annually, the population will double in 3.5 years.

Carrying Capacity

Every population experiences rising and falling growth due to environmental factors, social changes, food availability, and disease.

KEY IDEA

The peak number of individuals of a species supported in a sustainable manner by an ecosystem is called its *carrying capacity.*

At times a population overshoots available resources and death rates are higher than birth rates. This causes a negative growth curve and a population crash generally follows. Figure 11.2 illustrates the oscillating population surge and crash to either side of an environment's carrying capacity.

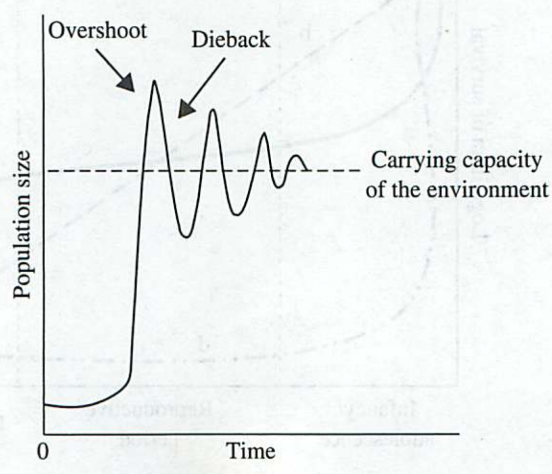


Figure 11.2 Populations increase/decrease with respect to their environment's carrying capacity.

Population Growth

Some populations grow more slowly for internal and external reasons. Internal factors include hormone regulation, maturity, and body size. External growth limitations in the environment include food and habitat accessibility, as well as predator populations. Dense populations increase pressure on resources (e.g., food and water) and overcrowding, which causes increased stress and disease. These population factors are called *density-dependent limitations.* Other population limiters are *density-independent,* such as drought, early frost, fires, hurricanes, floods, earthquakes, and other environmental happenings. Things that lower population density and growth rates are known as *environmental resistance* factors.

A population may grow quickly for a time but then reach its carrying capacity and maintain a stable population size. When the growth rate changes to match local conditions, it is known as *logistic growth.* Logistic growth is described mathematically by the following equation, where K is the environment's carrying capacity.

$$rN\left(1-\frac{N}{K}\right)=\frac{\Delta N}{\Delta t}$$

STRATEGY

The change in population numbers over time ($\Delta N/\Delta t$) is equal to exponential growth over time (r times N) times the carrying capacity (K) of the population size (N). The term ($1 - N/K$) stands for the relationship between N, a point in time, and K, the number of individuals the environment is able to support. When N is less than K (e.g., 50 compared with 75), then ($1 - N/K$) is a positive number ($1 - 50/75 = 0.33$) and slow steady population growth results. However, if N is greater than K, 75 compared with 50, then ($1 - N/K$) is a negative number ($1 - 75/50 = -0.05$) and a population's growth exceeds its environmental carrying capacity. Logistic growth describes population drop when it overreaches carrying capacity.

Human Population Change

Humans travel to new locations for family, food, jobs, land, religious freedom, and to avoid war. Population movement from a place is known as *emigration.* When people join a population, it's called *immigration.* Population movement helps researchers predict overall resource requirements, diseases, and other factors important to policy planning. In fact, the U.S. Census Bureau reports an overall drop in the human world population growth rate since 1950 from a high of 2.2% to around 1% today. The projection predicts further decline, with a drop to about 0.4% by 2050.

Human population changes are also related to *replacement birth rate,* or the number of children a couple has to replace them in a population. Two seems the obvious answer, but children die in childhood and some couples don't have children, so statistically the human replacement birth rate can be as high as 2.5.

TIP

Culture, birth control availability, women's education, public and private retirement programs, child labor needs (e.g., farming), and religious beliefs all impact human fertility rates. Human population growth is also affected by death rates related to (1) mothers dying in childbirth and infant mortality, (2) infectious disease, (3) hazardous work conditions, (4) poor sanitation, (5) clean water supplies, (6) better health care, and (7) better and more available food.

Age–Structure Diagrams

Scientists construct *age–structure diagrams* to study population growth. These diagrams offer a quick way to see what's happening in a specific population and to predict trends. They are often plotted by age (e.g., pre-reproductive 0 to 14 years, reproductive 15 to 45 years, and post-reproductive 46 years and older). Figure 11.3 shows two human populations with different age–structure diagrams and population distributions. Population A has a fairly equal distribution, while population B has many more individuals in the pre-reproductive and reproductive age groups. Population B will have a steep future growth rate, with population A growing more slowly.

Policy makers and researchers also predict population trends based on birth and death rates. They use a *demographic transition model* where zero population growth results from high (↑) birth and death rates or low (↓) birth and death rates. When populations shift from one growth type to the other, it is known as demographic transition. There are generally four demographic types. These include

- *Preindustrial.* Population has a slow growth rate and ↑ birth and ↑ death rates due to difficult living conditions.
- *Transitional.* ↑ birth rates, but better living conditions, allow ↓ death rates and create fast population growth.
- *Industrial.* Population growth is slow with ↓ birth rates and ↓ death rates as seen in developing countries.
- *Postindustrial.* Population nears and reaches zero population growth. Some populations may even dip below the zero growth rate.

Figure 11.4 illustrates a demographic transition model.

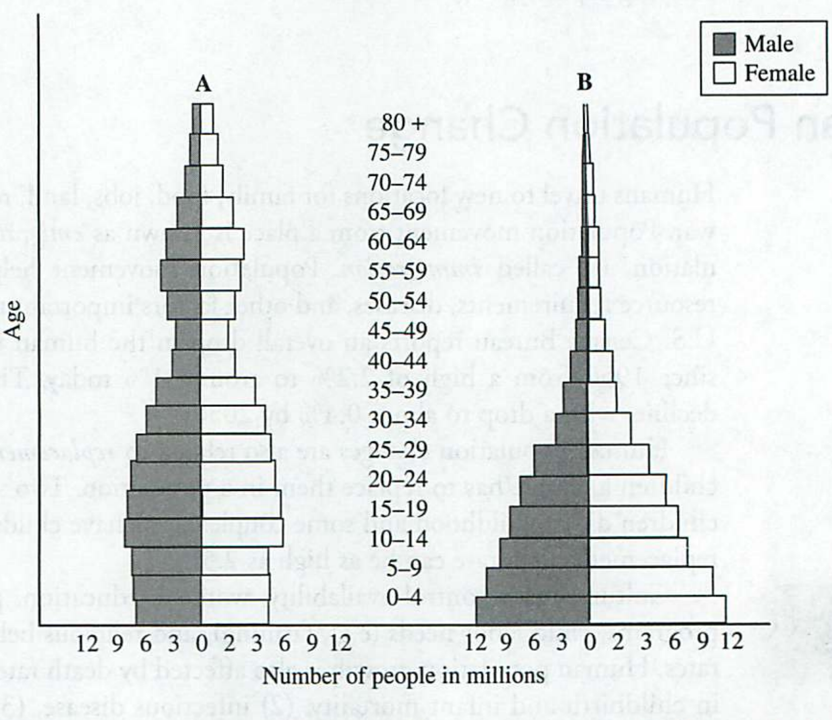


Figure 11.3 Age–structure diagrams allow scientists to study populations and predict trends.

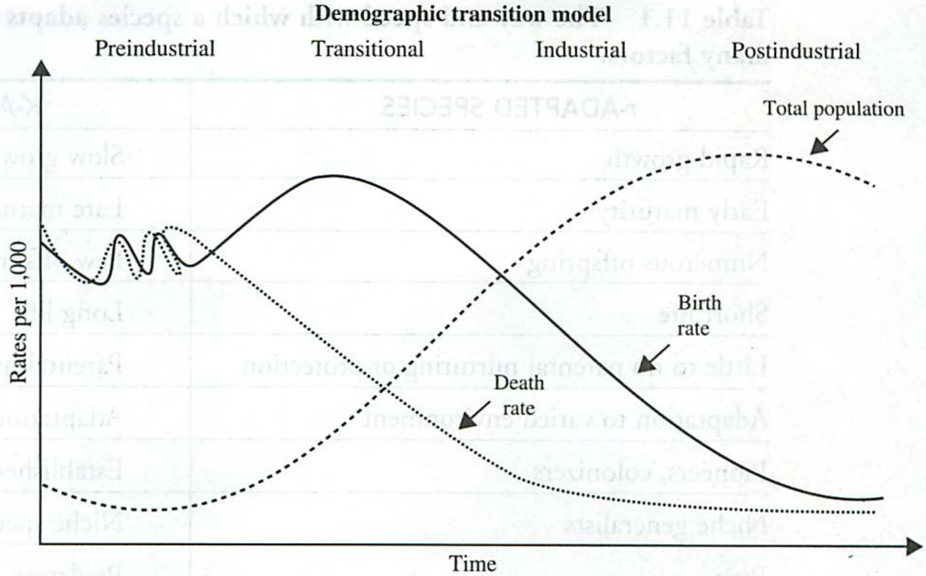


Figure 11.4 Population growth shifts follow four basic demographic transition types.

Population Density

Population density is affected by internal (within the population, like survivorship) factors, as well as external (e.g., environmental) factors. These can be further broken down into *biotic* (e.g., living organisms like the plague) or *abiotic* factors (related to nonliving elements like drought). How these various influences affect a population is also *density dependent* or *density independent*. For example, the plague has a higher mortality rate and spreads faster in a dense population than in a population where individuals are farther apart. Drought and volcanic eruptions are density independent, affecting populations in the same area in the same way whether they are densely packed or not.

TIP

Density-dependent factors are less random and affect populations more as density increases. For example, if habitat is lost or food eaten, competition for resources grows. Fighting between and within species, lack of females, stress, low birth rates, and disease all increase. Overcrowding forces predators closer to their prey. When this happens, old and sick individuals are killed by predators, but the herd becomes stronger.

Species Adaptation

Species can also be categorized in the ways in which they adapt to their environment. The first, known as *r-adapted species*, produce lots of offspring and have a high rate of growth (rN). These opportunistic species are generally lower on the food web and use great numbers of offspring to ensure species survival. Weeds, such as dandelions, which spread almost overnight in a lawn, fit into this category.

TIP

Long-lived species, which produce slower maturing and fewer offspring, like elephants (e.g., reaching reproductive maturity around age 20 and giving birth only every 4 to 5 years), maintain a generally stable population with the carrying capacity (K) of their environment. Elephants, then, are called *K-adapted species*, and tend to live 60 to 70 years if not heavily impacted by density-independent factors such as habitat loss or heavy poaching. Adaptation strategies are detailed in Table 11.1.

Table 11.1 The way and speed with which a species adapts is dependent on many factors.

r-ADAPTED SPECIES	*K*-ADAPTED SPECIES
Rapid growth	Slow growth
Early maturity	Late maturity
Numerous offspring	Few offspring
Short life	Long life
Little to no parental nurturing or protection	Parental nurturing and protection
Adaptation to varied environment	Adaptation to stable environment
Pioneers, colonizers	Established conditions
Niche generalists	Niche specialists
Prey	Predators
Affected by internal factors	Affected by external factors
Low on food web	High on food web

Conservation Biology

The old saying "You can't fool Mother Nature" seems to be true when predicting, protecting, and assessing species populations. Conservation biologists are only beginning to understand all the physiological and environmental factors that regulate populations. Add in human pressures from overfishing, overhunting, and habitat destruction, and you begin to see the complexity of the problem.

However, some geographically isolated populations are classified as *island biogeographic*. Geographic isolation has pros and cons for a population. Things that barely disturb a diverse, unrestrained population (e.g., disproportion between the number of males and females) can annihilate an isolated population. This is particularly true for isolated populations when genetic diversity narrows due to few or no new individuals coming into the population. For recessive traits to be balanced out, a certain number of individuals with dominant and healthy traits need to reproduce. In a big population, new genes are always circulating among mating individuals and the population remains healthy.

However, with limited numbers of breeding pairs on an island, a mutation would be passed on through subsequent generations unequally. When a species is isolated long enough, loss of genetic diversity may affect reproduction, adaptability, and species survival. This founder effect, mentioned in Chapter 9, plays a part in genetic drift.

STRATEGY

Conservation biologists study isolation, genetic drift, and founder effect to figure out the minimum viable population size, which is the lowest number of individuals needed for a species' continued survival. For example, in North America, the grizzly bear numbered around 100,000 in 1800 and occupied an area from the Midwest to the Pacific Ocean. Today, fewer than 1,000 grizzlies occupy six areas on less than 1% of their previous range. Yellowstone National Park in Wyoming has around 200 grizzly bears. Conservationists aren't sure if this low number can sustain genetic viability and avoid problems if the

Yellowstone population becomes even more isolated through resource and habitat loss. Even introducing a few genetically diverse bears every few generations helps increase population viability.

Impacts of Population Growth

Because of population growth, humans have impacted the Earth's resources more than any other species. The availability of clean water, sanitation, improved medical treatments, and advanced food production methods have all lengthened the average human life span and added to global population growth.

Historically, many countries have been able to feed their populations with local resources. However, population growth increases food demand and the demands on these resources. Some regions (e.g., Latin America), previously self sufficient, must now import grain and other products to feed their growing populations.

Land Use

Land overuse results from economic circumstances, poor land laws, and cultural customs. Some people exploit land resources for their own gain with little thought for the land or neighboring areas. Some people in poverty have little choice but to overuse their meager resources, even to the extent of wearing out the land. Trade and exploitation of a country's natural resources often leaves land restoration in the hands of local people without any funding.

Wars and national emergencies also destroy rich land by overburdening it with refugees and other displaced people. Natural disasters like floods and droughts can do the same thing. All this limits environmental resources needed for regional populations to maintain population growth and health.

Resource Distribution

Some charities (e.g., local food banks and national agencies) exist that redistribute food. They get food from growers, food processors, and distributors, and then make the food available at low prices to needy people.

Internationally, groups like the World Trade Organization have policies controlling international trade. However, developing countries are often at a disadvantage since they have used many of their resources and have nothing to export except labor. In order to secure work for their population, these companies often bid for international labor contracts at very low prices. This does little to pull them out of a continuing cycle of poverty.

Population Control

Efforts to control population include birth control and education (especially of women). Some countries, such as China with extreme overpopulation over 1.4 billion people, limit population growth by enacting laws (e.g., one child only per couple) to raise everyone's standard of living and prevent hunger and poverty resulting from unrestrained population growth. China's One Child Policy, though controversial in the West due to female gender discrimination, has resulted in a decrease in the population growth of that country by approximately 250 million.

› Review Questions

Multiple-Choice Questions

1. Change in gene frequency is known as

(A) mitosis
(B) genetic drift
(C) hybridization
(D) genetic optimization
(E) founder effect

2. Which term is used to describe the longest time interval a certain species is estimated to live?

(A) Mortality
(B) Nutrition
(C) Decades
(D) Life span
(E) Fertility

3. When populations experience an unrestricted overshoot before limited resources, space, or disease cause a dieback, it is known as

(A) logarithmic growth
(B) a *p* curve
(C) exponential growth
(D) proven reserves
(E) biotic exponential

4. Fecundity is the actual capability to reproduce, while number of offspring produced is a measure of

(A) ecological succession
(B) natality
(C) survivorship
(D) fertility
(E) niche development

5. The rule of 70 is used to estimate

(A) entrepreneurial species
(B) population doubling
(C) density-dependent species
(D) infant development
(E) potential of a new Starbucks in a neighborhood

6. Movement out of a population is known as

(A) delinquency
(B) mortality
(C) emigration
(D) suburban sprawl
(E) immigration

7. The number of years an individual is statistically likely to live is called his or her

(A) species duration
(B) natality
(C) life expectancy
(D) mortality
(E) genetic drift

8. Isolation, genetic drift, and founder effect help biologists figure out

(A) species adaptability
(B) succession level
(C) mutualism
(D) maximum viable population size
(E) minimum viable population size

9. Biotic potential is defined by which of the following equations?

(A) $rN = \Delta N/\Delta t$
(B) $rN = \frac{1}{2}\Delta N - t$
(C) $rN = \Delta t/\Delta N$
(D) $rN = \Delta t/N/K$
(E) $rN(1 - N/K) = \Delta N/\Delta t$

10. When a species produces lots of offspring and has a high rate of growth (rN), it is known as a

(A) pioneer species
(B) K-adapted species
(C) long-lived species
(D) r-adapted species
(E) foundational species

11. Preindustrial populations usually have slow growth rates and

(A) low economic potential
(B) ↑ birth and ↑ death rates
(C) low geographic resources
(D) ↓ birth and ↑ death rates
(E) ↓ birth and ↓ death rates

12. Biotic and abiotic factors greatly affect

(A) population density
(B) niche development
(C) fecundity
(D) education levels
(E) genetic drift

13. Human population control

(A) has never worked
(B) has reaped substantial benefits in China
(C) is impossible in developed nations
(D) is not needed with a slowing global population
(E) is not possible with today's technology

14. A group of individuals of the same species in the same geographical area is known as a

(A) herd
(B) niche
(C) population
(D) system
(E) flock

15. Exponential human population growth is affected by all the following factors except

(A) infectious disease
(B) clean water supplies
(C) hazardous work conditions
(D) increased television time
(E) better and more available food

16. The germination, cloning, birth, or hatching of individuals in a population is known as

(A) life span
(B) niche
(C) mortality
(D) genetic drift
(E) natality

17. The number of individuals born at or near the same time and living to a specific age is called

(A) survivorship
(B) natality
(C) mortality
(D) fecundity
(E) immigration

18. When a species is isolated long enough, loss of genetic diversity may affect reproduction, adaptability, and species survival. This is known as

(A) *r*-adapted species
(B) *K*-adapted species
(C) founder effect
(D) logistic growth
(E) demographic transition

19. When a population's growth rate changes to match local conditions, it is known as

(A) exponential growth
(B) density-independent growth
(C) natality
(D) logistic growth
(E) pioneer growth

› Answers and Explanations

1. B—New genes changing and circulating in a population keep the species healthy.

2. D—The longest recorded human life span is 122 years.

3. C—The unrestricted growth rate is expressed as a fraction or exponent by which the starting population is multiplied.

4. D—Rabbits are more fertile (many babies often) than elephants (one baby infrequently).

5. B—By dividing 70 by the annual percent rate of growth, you get a population's estimated doubling time.

6. C—People coming into an established population are called immigrants.

7. C—The life expectancy for a specific person is not set but affected by many factors.

8. E—Introducing genetically diverse individuals increases population viability.

9. A

10. D—These species are lower on the food web and produce great numbers of offspring.

11. B—This is due to hard living conditions and primitive medical care.

12. A—Fighting between species, lack of females, stress, low birth rates, and disease, along with tornadoes, flash floods, and drought, affect population.

13. B—By slowing population growth, China can better meet its food needs.

14. C

15. D

16. E—It is affected by external factors such as climate and temperature.

17. A—Survivorship is an internal population density factor.

18. C—The isolated population often has a tough time adapting to new conditions.

19. D—This is known as logistic growth and is equal to a population's carrying capacity.

Free-Response Questions

1. Most people blame desertification on overpopulation. However, it's possible for large populations to practice good conservation and avoid desertification. It is said the United States could feed most of the world with all the grain produced in the Midwest. However, the Ogallala Aquifer, which provides most of the water for irrigation there, has been overmined for years. Crop irrigation there might not be possible in another 25 to 40 years.

Desertification is a complex problem since a decrease in population can also cause desertification because there are less people to take care of the land. In some countries, when young people in villages go into the city to find work, their aging parents can't keep up with the land's needs and cultivation.

(a) What are some conservation and land management methods large populations can use to prevent desertification?

(b) Describe three impacts (other than desertification) human population growth has had on the environment.

(c) How could overmining of the Ogallala Aquifer change the carrying capacity of the "grain belt"?

Free-Response Answers and Explanations

1.

a. Rotational grazing can be used to help increase the health of grasslands by reducing the stress cattle place on the environment through overgrazing, while maximizing the positive effects (e.g., fertilization) cattle have on grasslands. Proper forestry and irrigation techniques can also help, as well as cultural and lifestyle changes to reduce dependence on traditional land use.

b. Human population growth has affected the world in ways far greater than that of any other species. Redistribution (or lack of) of resources (e.g., land, water, oil, and other fossil fuels) according to population needs has reshaped the environment in countless ways, from the building of roadways to war and famine. Our agricultural practices have led to increased life spans, which in turn continuously limit the amount of available resources. Many countries and regions, once self-sufficient (e.g., Latin America) must now import resources to sustain their growing populations.

c. The huge loss of water for irrigation due to overmining the Ogallala Aquifer would drastically reduce the region's carrying capacity. By "living beyond their means," local populations and those benefiting from grain sales have created a possible future where grain shortages could lead to massive socioeconomic and environmental changes.

❯ Rapid Review

- Exponential growth happens when populations experience an unrestricted growth overshoot before limited resources and space or disease cause slowing.
- Logistics growth describes population drop when it overreaches carrying capacity.
- A group of individuals of the same species located in the same geographic area is known as a population.
- When a species is isolated long enough, loss of genetic diversity may affect reproduction, adaptability, and species survival. This is known as the founder effect.
- Fertility is only half the answer to exponential human population growth. The other half comes from the drop in death rates related to (1) mothers dying in childbirth and infant mortality, (2) infectious disease, (3) hazardous work conditions, (4) poor sanitation, (5) clean water supplies, (6) better health care, and (7) better and more available food.
- Natality (i.e., germination, cloning, birth, or hatching of new individuals in a population) is affected by external factors (e.g., climate, temperature, moisture, and soil), which determine whether a population will grow or shrink.
- Fecundity is the actual capability to reproduce, while fertility is a measure of the number of offspring produced.
- Life span describes the longest interval of time that a certain species is estimated to live.
- Life expectancy is the likely number of years an individual is expected to live based on statistical probability.
- Mortality is calculated by dividing the number of individuals that die during a specific time period by the number alive at the start of that same time period.
- Survivorship describes the number of individuals born at or near the same time and living to a specific age.

- The first species to inhabit an area is called a pioneer species.
- External growth limitations in the environment include food and habitat accessibility, as well as predator numbers.
- Mortality or death rate is an internal factor that can be increased or decreased by external conditions such as extreme heat or cold.
- Movement out of or away from a population is known as emigration.
- When individuals join a population, it is called immigration.
- Population limiters, such as drought, early frost, fires, hurricanes, floods, earthquakes, and other environmental happenings, are density independent.
- Things that lower population density and growth rates are called environmental resistance factors.
- The r component in $rN = \Delta N/\Delta t$ describes the average contribution of an individual to population growth. This equation finds a species' *biotic potential.*
- The rule of 70 is used to estimate population doubling. By dividing 70 by the annual percent rate of growth, you get a population's approximate doubling time in years.
- Logistic growth is described mathematically by $rN\,(1 - N/K) = \Delta N/\Delta t$, where K is an environment's carrying capacity.
- Conservation biologists study isolation, genetic drift, and the founder effect to find the minimum viable population size or lowest number of individuals for a species' survival.