CHAPTER 11

Diversity Within Species

11

Chapter Outline

Key Concepts	Applications
Understand the difference in meaning between the terms *species* and *population*.	• Understand the criteria for distinguishing one species from another. • Understand that the definition for species allows for species designations to be changed.
Describe the occurrence of a gene in a population in terms of gene frequency.	• Describe the difference between the biological species concept and the morphological species concept. • Describe why all organisms of a species are not the same. • Understand the meaning of the term *gene pool*. • Appreciate the significance of genetic diversity.
Relate the concepts of cloning and hybridization to asexual and sexual reproduction.	• Describe how hybrid plants are produced. • Recognize how different breeds of animals are produced. • Recognize the importance and potential danger of the practice of monoculture.
Recognize the factors that can change gene frequencies.	• Describe how differences in gene frequency are produced through mutation, sexual reproduction, population size, and migration. • Describe why different populations of the same species often have different gene frequencies.
Recognize that population genetics principles apply to human populations.	• Describe why certain diseases are more common in some groups of people than in others. • Understand what meaning "race" has in the human species. • Describe the role of a genetic counselor. • Understand how misunderstanding of population genetics resulted in eugenics movements.

11.1 Populations and Species

To understand the principles of genetics in chapter 10, we concerned ourselves with small numbers of organisms having specific genotypes. When these organisms reproduced, we could predict the probability of an allele being passed to the next generation. Plants, animals, and other kinds of organisms, however, don't exist as isolated individuals but as members of populations. Since populations typically consist of large numbers of individuals each with its own set of alleles, populations contain many more possible alleles than a few individuals involved in a breeding experiment. Before we go any further, we need to develop a clear understanding of two terms that are used throughout this chapter, *population* and *species*.

The concepts of population and species are interwoven: A **population** is considered to be all the organisms of the same species found within a specific geographic region. A population is primarily concerned with numbers of organisms in a particular place at a particular time. A standard definition for species is that a **species** is a population of all the organisms potentially capable of breeding naturally among themselves and having offspring that also interbreed. *An individual organism is not a species but is a member of a species.* This definition of a species is often called the **biological species concept** and involves an understanding that organisms of different species do not interchange genes. Most populations consist of a portion of the members of a species, as when we discuss the wolves of Yellowstone National Park or the dandelion population in a city park. At other times it is possible to consider all the members of a species as being one large population, as when we talk about the human population of the world or the current numbers of the endangered whooping crane.

11.2 The Species Problem

A clear understanding of the concept of a species is important as we begin to consider how genes are passed around within populations as sexual reproduction takes place. If you examine the chromosomes of reproducing organisms, you find that they are identical in number and size and usually carry very similar groups of genes. In the final analysis, the biological species concept assumes that the genetic similarity of organisms is the best way to identify a species regardless of where or when they exist.

Often, organisms that are known to belong to distinct species differ in one or more ways that allow us to recognize them as separate species. Therefore, it is common to differentiate species on the basis of key structural characteristics. This method of using structural characteristics to identify species is called the **morphological species concept.** Structural differences are useful but not foolproof ways to distinguish species. However, we must rely on such indirect ways to identify species because we cannot possibly test every individual by breeding it with another to see if they will have fertile offspring. Furthermore, many kinds of organisms reproduce primarily by asexual means. Because organisms that reproduce exclusively by asexual methods do not exchange genes with any other individuals, they do not fit our *biological species* definition very well.

Several other techniques are also used to identify species. Among animals, differences in behavior are often useful in identifying species. Some species of birds and insects are very similar structurally but can be easily identified by differences in the nature of their songs. Among bacteria, fungi, and other microorganisms, the presence or absence of specific chemicals within the organism is often used to help distinguish among species.

Conversely, the structure or behavior of an organism may mislead people into assuming that two organisms are different species when actually they represent the extremes of variation within a species. Many plants have color variations or differences in leaf shape that cause them to look quite different although they are members of the same species. The eastern gray squirrel has black members within the species that many people assume to be a different species because they are so different in color. A good example of the genetic variety within a species is demonstrated by the various breeds of dogs. A Great Dane does not look very much like a Pekinese. However, mating can occur between these two very different-appearing organisms (figure 11.1). They are of the same species.

Finally, we have situations where individuals of two recognized species interbreed to a certain degree. Dogs, coyotes, and wolves have long been considered separate species. Differences in behavior and social systems tend to prevent mating among these three species. Wolves typically compete with coyotes and kill them when they are encountered. However, natural dog-coyote, wolf-coyote, and wolf-dog hybrids occur and the young are fertile (How Science Works 11.1). In fact, people have purposely encouraged mating between dogs and wolves for a variety of reasons. It is commonly thought that dogs are descendants of wolves that have been domesticated, so it should not be surprising that mating between wolves and dogs is easy to accomplish. The question then becomes, because matings do occur and the offspring are fertile, "Should dogs and wolves be considered members of the same species?" There is no simple answer to the question.

The species concept is an attempt to define groups of organisms that are reproductively isolated and, therefore, constitute a distinct unit of evolution. We must accept that some species will be completely isolated from other closely related species and will fit the definition well; some will have occasional gene exchange between species and will not fit the definition as well; and some groups interbreed so much that they must be considered distinct populations of the same species. Throughout the next several chapters we will use the term *species,* complete with its flaws and shortcomings, because it is a useful way to identify groups of organisms

(a)

(b)

(c)

(d)

Figure 11.1

Genetic Variety in Dogs
Although these four breeds of dogs look quite different, they all have the same number of chromosomes and are capable of interbreeding. Therefore, they are members of the same species. The considerable difference in phenotypes is evidence of the genetic variety among breeds—(*a*) golden retriever, (*b*) dalmatian, (*c*) dingo, (*d*) Pekinese.

HOW SCIENCE WORKS 11.1

Is the Red Wolf a Species?

The red wolf (*Canis rufus*) is listed as an endangered species, so the U.S. Fish and Wildlife Service has instituted a captive breeding program to preserve the animal and reintroduce it to a suitable habitat in the southeastern United States, where it was common into the 1800s. Biologists have long known that red wolves will hybridize with both the coyote, *Canis latrans,* and the gray wolf, *Canis lupus,* and many suspect that the red wolf is really a hybrid between the gray wolf and the coyote. Gray wolf–coyote hybrids are common in nature where one or the other species is rare. Some have argued that the red wolf does not meet the definition of a species and should not be protected under the Endangered Species Act.

Museums have helped shed light on this situation by providing skulls of all three kinds of animals preserved in the early 1900s. It is known that during the early 1900s as the number of red wolves in the southeastern United States declined, they readily interbred with coyotes, which were very common. The gray wolf had been exterminated by the early 1900s. Some scientists believe that the skulls of the few remaining "red wolves" might not represent the true red wolf but a "red wolf" with many coyote characteristics. Studies of the structure of the skulls of red wolves, coyotes, and gray wolves show that the red wolves were recognizably different and intermediate in structure between coyotes and gray wolves. This supports the hypothesis that the red wolf is a distinct species.

DNA studies were performed using material from preserved red wolf pelts. The red wolf DNA was compared to coyote and gray wolf DNA. These studies show that red wolves contain DNA sequences typical of both gray wolves and coyotes but do not appear to have distinct base sequences found only in the red wolf. These studies support the hypothesis that the red wolf is not a species but a population that resulted from hybridization between gray wolves and coyotes.

There is still no consensus on the status of the red wolf. Independent researchers disagree with one another and with Fish and Wildlife Service scientists, who have been responsible for developing and administering a captive breeding program and planning reintroductions of the red wolf.

that have great genetic similarity and maintain a certain degree of genetic separateness from all similar organisms.

There is one other thing you need to be careful about when using the word *species*. It is both a singular and plural word so you can talk about a single species or you can talk about several species. The only way you can tell how the word is being used is by assessing the context of the sentence.

11.3 The Gene Pool Concept

We have just related the species concept to genetic similarity; however, you know that not all individuals of a species are genetically identical. Any one organism has a specific genotype consisting of all the genes that organism has in its DNA. It can have a maximum of two different alleles for a characteristic because it has inherited an allele from each parent. In a population, however, there may be many more than two alleles for a specific characteristic. In humans, there are three alleles for blood type (A, B, and O) within the population, but an individual can have only up to two of the alleles. Because, theoretically, all organisms of a species are able to exchange genes, we can think of all the genes of all the individuals of the same species as a giant **gene pool.**

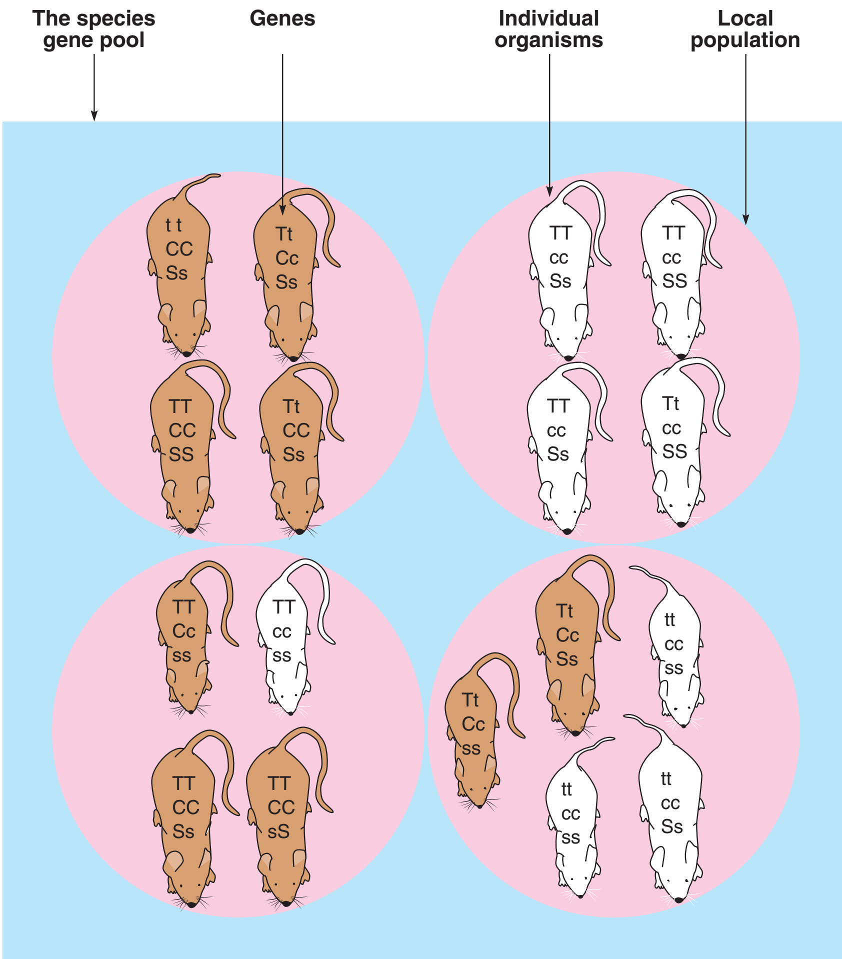

Figure 11.2

Genes, Populations, and Gene Pools
Each individual shown here has a specific genotype. Local breeding populations differ from one another in the frequency of each gene, but all local populations have each of the different genes represented within the population. The gene pool includes all the individuals present. Assume that T = long tail, t = short tail, C = brown color, c = white color, S = large size, and s = small size. Notice how the different frequencies of genes affect the appearance of the organisms in the different local populations.

Because each individual organism is like a container of a set of these genes, the gene pool contains many more variations of genes than any one of the individuals. The gene pool is like a refrigerator full of cartons of different kinds of milk—chocolate, regular, skim, buttermilk, low-fat, and so on. If you were blindfolded and reached in with both hands and grabbed two cartons, you might end up with two chocolate, a skim and a regular, or one of the many other possible combinations. The cartons of milk represent different alleles, and the refrigerator (gene pool) contains a greater variety than could be determined by randomly selecting two cartons of milk at a time.

Individuals of a species usually are not found evenly distributed within a region but occur in clusters as a result of factors such as geographic barriers that restrict movement or the local availability of resources. Local populations with distinct gene clusters may differ quite a bit from one place to another. There may be differences in the kinds of alleles and the numbers of each kind of allele in different populations of the same species. Figure 11.2 indicates the relationship of alleles to individuals, individuals to populations, and populations to the entire gene pool. Note, for example, that although all the populations contain the same kinds of alleles, the relative number of alleles *T* and *t* differ from one population to another.

Because organisms tend to interbreed with other organisms located close by, local collections of genes tend to remain the same unless, in some way, genes are added to or subtracted from this local population. Water snakes are

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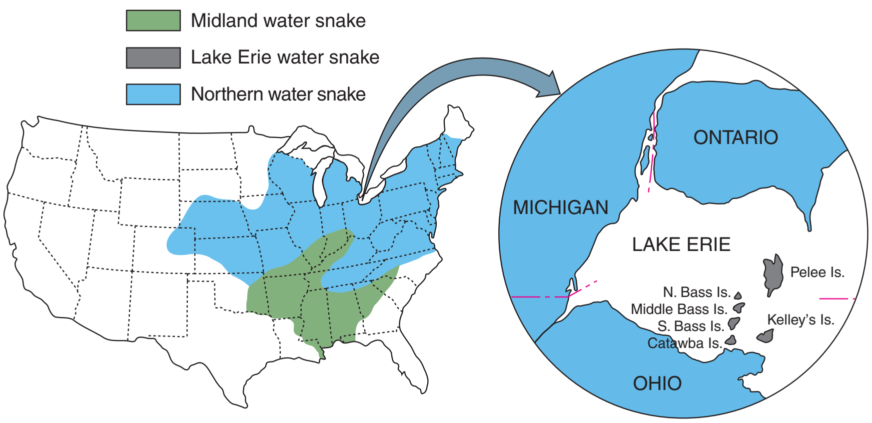


Northern water snake

Lake Erie water snake

Figure 11.3

The Range and Appearance of the Northern Water Snake and the Lake Erie Water Snake
The northern water snake is found throughout the northeastern part of the United States and extends into Canada. The Lake Erie water snake is limited to the islands in the western section of Lake Erie. A third variation, the midland water snake, is found south of the northern water snake.

found throughout the eastern portion of the United States (figure 11.3). The Lake Erie water snake, which is confined to the islands in western Lake Erie, is one of the several distinct populations within this species. The northern water snakes of the mainland have light and dark bands. The island populations do not have this banded coloration. Most island individuals have alleles for solid coloration; very few individuals have alleles for banded coloration. The island snakes are geographically isolated from the main gene pool and mate only with one another. Thus, the different color patterns shown by island snakes and mainland snakes result from a high incidence of solid-color alleles in the island populations and a high incidence of banded-color alleles in the mainland populations.

Within a population, genes are repackaged into new individuals from one generation to the next. Often there is very little adding or subtracting of genes from a local group of organisms, and a widely distributed species will consist of a number of more or less separate groups that are known as **subspecies, races, breeds, strains,** or **varieties.** All these terms are used to describe different forms of organisms that are all members of the same species. However, certain terms are used more frequently than others, depending on one's field of interest. For example, dog breeders use the term *breed,* horticulturalists use the term *variety,* microbiologists use the term *strain,* and anthropologists use the term *race* (Outlooks 11.1). The most general and widely accepted term is *subspecies.*

11.4 Describing Genetic Diversity

Throughout the next three chapters you will need to watch several terms carefully. **Genetic diversity** is a term used to described genetic differences among members of a population. High genetic diversity indicates many different kinds of alleles for each characteristic, and low genetic diversity indicates that nearly all the individuals in the population have the same alleles. In general, the term **gene frequency** is used when discussing how common genes are within populations. The term **allele frequency** is more properly used when specifically discussing how common a particular form of a gene (allele) is compared to other forms.

Allele frequency is commonly stated in terms of a percentage or decimal fraction (e.g., 10% or 0.1; 50% or 0.5). It is a mathematical statement of how frequently a particular allele is found in a population. It is possible for two populations of the same species to have all the same alleles but with very different frequencies.

As an example, all humans are of the same species and, therefore, constitute one large gene pool. There are, however, many distinct local populations scattered across the surface of the Earth. These more localized populations (races) show many distinguishing characteristics that have been perpetuated from generation to generation. In Africa, alleles for dark skin, tightly curled hair, and a flat nose have very high frequencies. In Europe, the frequencies of alleles for light skin, straight hair, and a narrow nose are the

OUTLOOKS 11.1

Biology, Race, and Racism

The concept of racial difference among groups of people must be approached carefully. Two distortions can occur when people use the term *race*. First, the designation of race focuses on differences, most of which are superficial. Skin color, facial features, and the texture of the hair are examples. Although these examples are easy to see, they are arbitrary, and emphasis on them tends to obscure the fact that humans are all fundamentally the same, with minor variations in the frequency of certain alleles.

A second problem with the concept of race is that it is very difficult to separate genetic from cultural differences among people. People tend to equate cultural characteristics with genetic differences. Culture is learned and, therefore, is an acquired characteristic not based on the genes a person inherits. Cultures do differ, but these differences cannot be used as a basis for claiming genetic distinctions.

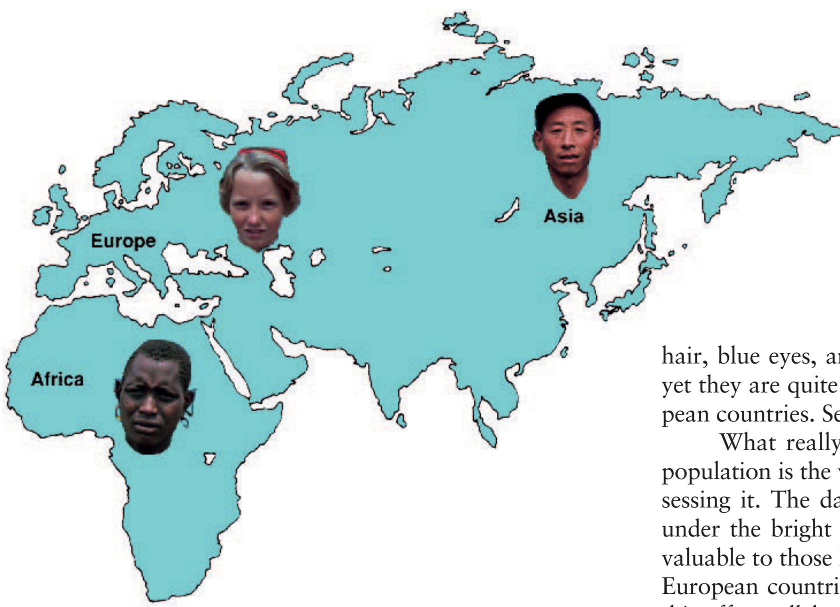


Figure 11.4

Gene Frequency Differences Among Humans
Different physical characteristics displayed by people from different parts of the world are an indication that gene frequencies differ as well.

highest. People in Asia tend to have moderately colored skin, straight hair, and broad noses (figure 11.4). All three of these populations have alleles for dark skin and light skin, straight hair and curly hair, narrow noses and broad noses. The three differ, however, in the frequencies of these alleles. Once a particular mixture of alleles is present in a population, that mixture tends to maintain itself unless something is operating to change the frequencies. In other words, allele frequencies are not going to change without reason. With the development of transportation, more people have moved from one geographic area to another, and human allele frequencies have begun to change. Ultimately, as barriers to interracial marriage (both geographic and sociological) are leveled, the human gene pool will show fewer and fewer racial differences.

For some reason, people tend to think that the frequency of alleles has something to do with dominance or recessiveness. This is not true. Often in a population, recessive alleles are more frequent than their dominant counterparts. Straight hair, blue eyes, and light skin are all recessive characteristics, yet they are quite common in the populations of certain European countries. See table 11.1 for other examples.

What really determines the frequency of an allele in a population is the value that the allele has to the organisms possessing it. The dark-skin alleles are valuable to people living under the bright sun in tropical Africa. These alleles are less valuable to those living in the less intense sunlight of the cooler European countries. This idea of the value of alleles and how this affects allele frequency will be dealt with more fully when the process of natural selection is discussed in chapter 12.

11.5 Why Genetically Distinct Populations Exist

Because individual organisms within a population are not genetically identical, some individuals may possess genetic combinations that are particularly valuable for survival in the local environment. As a result, some individuals find the environment less hostile than do others. The individuals with unfavorable genetic combinations leave the population more often, either by death or migration, and remove their genes from the population. Therefore, local populations that occupy sites that differ greatly would be expected to consist of individuals having gene combinations suited to local conditions. For example, a blind fish living in a lake is at a severe disadvantage. A blind fish living in a cave where there is no light, however, is not at the same disadvantage. Thus,

Table 11.1

RECESSIVE TRAITS WITH A HIGH FREQUENCY OF EXPRESSION

Many recessive characteristics are extremely common in some human populations. The corresponding dominant characteristic is also shown here.

Recessive	Dominant
Light skin color	Dark skin color
Straight hair	Curly hair
Five fingers	Six fingers
Type O blood	Type A or B blood
Normal hip joints	Dislocated hip birth defect
Blue eyes	Brown eyes
Normal eyelids	Drooping eyelids
No tumor of the retina	Tumor of the retina
Normal fingers	Short fingers
Normal thumb	Extra joint in the thumb
Normal fingers	Webbed fingers
Ability to smell	Inability to smell
Normal tooth number	Extra teeth
Presence of molars	Absence of molars

Figure 11.5

Blind Cave Fish
The fish lives in caves where there is no light. Its eyes do not function and it has very little color in its skin. Because of its unusual habitat, the presence of genes for eyes and skin color is not important. If, at some time in the past, these genes were lost or mutated, it did not negatively affect the organism; hence, the present population has high frequencies of genes for the absence of color and eyes.

these two environments might allow or encourage characteristics to be present in the two populations at different frequencies (figure 11.5).

A second mechanism that tends to create genetically distinct populations with unique allele frequencies involves the founding of a new population. The collection of alleles from a small founding population is likely to be different from that present in the larger parent population from which they came. After all, a few individuals leaving a population would be unlikely to carry copies of all the alleles found within the original population. They may even carry an unrepresentative mixture of alleles. This situation in which a genetically distinct local population is established by a few colonizing individuals is know as the **founder effect.** For example, it is possible that the Lake Erie water snake discussed earlier was founded by a small number of individuals from the mainland that had a high frequency of alleles for solid coloration rather than the more typical banded pattern. (It is even possible that the island populations could have been founded by one fertilized female.) Once a small founding population establishes itself, it tends to maintain its collection of alleles because the organisms mate only among themselves. This results in a reshuffling of alleles from generation to generation and discourages the introduction of new genetic information into the population.

A third cause of local genetically-distinct populations relates to the past history of the population. Some local populations, and occasionally entire species, have reduced genetic diversity because their populations were severely reduced in the past. When the size of a population is greatly reduced it is likely that some genes will be lost from the population. Such a population reduction that results in reduced genetic diversity is called a **genetic bottleneck.** Any subsequent increase in the size of the population by reproduction among the remaining members of the population will not replace the genetic diversity lost. There are thousands of species that are currently undergoing genetic bottlenecks. Although some endangered species were always rare, most have experienced recent reductions in their populations and a reduction in genetic variety, which is a consequence of severely reduced population size.

A fourth factor that tends to encourage the maintenance of genetically distinct populations is the presence of barriers to free movement. Animals and plants that live in lakes tend to be divided into small, separate populations by barriers of land. Whenever such barriers exist, there will very likely be differences in the allele frequencies from lake to lake because each lake was colonized separately and their environments are not identical. Other species of organisms like migratory birds (robins, mallard ducks) experience few barriers; therefore, subspecies are quite rare.

11.6 How Genetic Diversity Comes About

A large gene pool with great genetic diversity is more likely to contain some gene combinations that will allow the organisms to adapt to a new environment. A number of mechanisms introduce this necessary variety into a population.

Mutations

Mutations introduce new genetic information into a population by modifying genes that are already present. Sometimes a mutation is a first-time event; other times a mutation may have occurred before. All alleles for a particular trait originated as a result of mutations some time in the past and have been maintained within the gene pool of the species as a result of sexual reproduction. If a mutation produces a harmful allele, it will remain uncommon in the population. Many mutations are harmful and very rarely will one occur that is valuable to the organism. For example, at some time in the past, mutations occurred in the DNA of certain insect species that made some individuals tolerant to the insecticide DDT, even though the chemical had not yet been invented. These alleles remained very rare in these insect populations until DDT was used. Then, these alleles became very valuable to the insects that carried them. Because insects that lacked the alleles for tolerance died when they came in contact with DDT, more of the DDT-tolerant individuals were left to reproduce the species and, therefore, the DDT-tolerant alleles became much more common in these populations.

Sexual Reproduction

Although the process of *sexual reproduction* does not create new genes, it tends to generate new genetic combinations when the genes from two individuals mix during fertilization, generating a unique individual. This doesn't directly change the frequency of alleles within the gene pool, but the new member may have a unique combination of characteristics so superior to those of other members of the population that the new member will be much more successful in producing offspring. In a corn population, there may be alleles for resistance to corn blight (a fungal disease) and resistance to attack by insects. Corn plants that possess both of these characteristics are going to be more successful than corn plants that have only one of these qualities. They will probably produce more offspring (corn seeds) than the others because they will survive fungal and insect attacks; moreover, they will tend to pass on this same genetic combination to their offspring (figure 11.6).

Migration

The *migration* of individuals from one genetically distinct population to another is also an important way for alleles to be added to or subtracted from a local population. Whenever an organism leaves one population and enters another, it subtracts its genetic information from the population it left and adds it to the population it joins. If it contains rare alleles, it may significantly affect the allele frequency of both populations. The extent of migration need not be great. As long as alleles are entering or leaving a population, the gene pool will change.

Many captive populations of animals in zoos are in danger of dying out because of severe inbreeding (breeding with near relatives) and the resulting reduced genetic variety. Most zoo managers have recognized the importance of increasing variety in their animals and have instituted programs of loaning breeding animals to distant zoos in an effort to increase genetic variety. In effect, they are simulating natural migration so that new alleles can be introduced into distant populations.

Many domesticated plants and animals also have significantly reduced genetic variety. Corn, wheat, rice, and other crops are in danger of losing their genetic variety. The establishment of gene banks in which wild or primitive relatives of domesticated plants are grown is one way that a source of genetic variety can be kept for later introduction if domesticated varieties are threatened by new diseases or environmental changes.

The Importance of Population Size

The *size of the population* has a lot to do with how effective any of these mechanisms are at generating variety in a gene pool. The smaller the population, the less genetic variety it can contain. Therefore, migrations, mutations, and accidental death can have great effects on the genetic makeup of a small population. For example, if a town has a population of 20 people and only two have brown eyes and the rest have blue eyes, what happens to those two brown-eyed people is more critical than if the town has 20,000 people and 2,000 have brown eyes. Although the ratio of brown eyes to blue eyes is the same in both cases, even a small change in a population of 20 could significantly change the frequency of the brown-eye allele.

11.7 Genetic Variety in Domesticated Plants and Animals

Humans often work with small, select populations of plants and animals in order to artificially construct specific gene combinations that are useful or desirable. This is particularly true of plants and animals used for food. If we can produce domesticated animals and plants with genes for rapid growth, high reproductive capacity, resistance to disease, and other desirable characteristics, we will be better able to supply ourselves with energy in the form of food. Plants are particularly easy to work with in this manner because we can often increase the numbers of specific organisms by asexual (without sex) reproduction. Potatoes, apple trees, strawberries, and many other plants can be reproduced by simply cutting the original plant into a number of parts and allowing these parts to sprout roots, stems, and leaves. If a single potato has certain desirable characteristics, it may be reproduced asexually. All of the individual plants reproduced asexually have exactly the same genes and are usually referred to as **clones.** Figure 11.7 shows how a clone is developed.

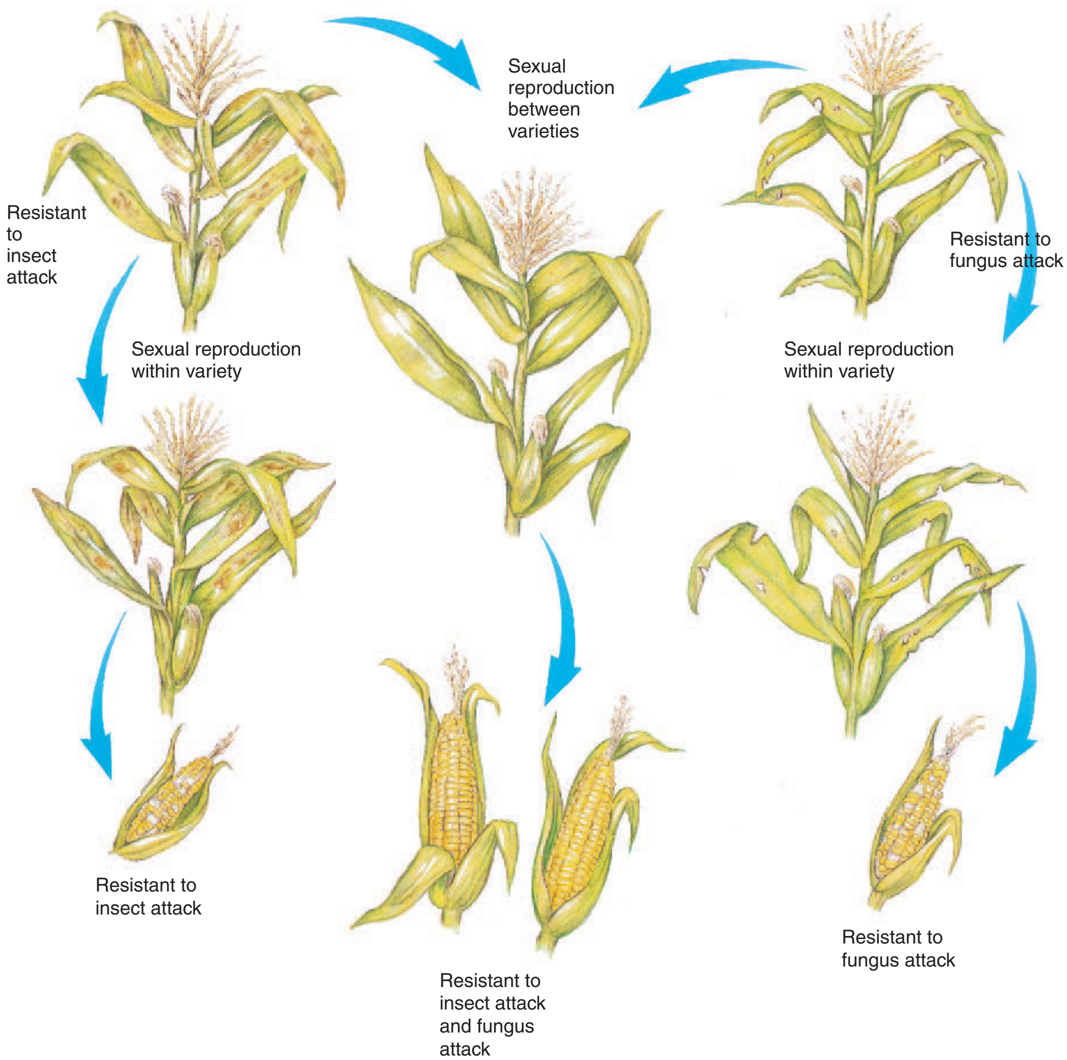


Figure 11.6

New Combinations of Genes
Sexual reproduction can bring about new combinations of genes that are extremely valuable. These valuable new gene combinations tend to be perpetuated.

Humans can also bring together specific combinations of genes in either plants or animals by selective breeding. This is not as easy as cloning. Because sexual reproduction tends to mix up genes rather than preserve desirable combinations of genes, the mating of individual organisms must be controlled to obtain the desirable combination of characteristics. Through selective breeding, some varieties of chickens have been developed that grow rapidly and are good for meat. Others have been developed to produce large numbers of eggs. Often the development of new varieties of domesticated animals and plants involves the crossing of individuals from different populations. For this technique to be effective, the desirable characteristics in each of the two varieties should have homozygous genotypes. In small, controlled populations it is relatively easy to produce individuals that are homozygous for one specific trait. To make two characteristics homozygous in the same individual is more difficult. Therefore, such varieties are usually developed by crossing two different populations to collect several desirable characteristics in one organism. The organisms that are produced by the controlled breeding of separate varieties are often referred to as **hybrids.**

Cuttings

A clone

Figure 11.7

Clones

All the plants in the right-hand photograph were produced asexually from cuttings and are identical genetically. The left-hand photograph shows how cuttings are made. The original plant is cut into pieces. Then the cut ends are treated with a growth stimulant and placed in moist sand or other material. Eventually, the pieces will root and become independent plants.

The kinds of genetic manipulations we have just described result in reduced genetic variety. Most agriculture in the world is based on extensive plantings of the same varieties of a species over large expanses of land (figure 11.8). This agricultural practice is called **monoculture.** The plants have been extremely specialized through selective breeding to have just the qualities that growers want. It is certainly easier to manage fields in which there is only one kind of plant growing. This is particularly true today when herbicides, insecticides, and fertilizers are tailored to meet the needs of specific crop species. However, with monoculture comes a significant risk.

Our primary food plants are derived from wild ancestors with combinations of genes that allowed them to compete successfully with other organisms in their environment. When humans use selective breeding within small populations to increase the frequency of certain desirable genes in our food plants, other valuable genes are lost from the gene pool. When we select specific good characteristics, we often get harmful ones along with them. Therefore, these "special" plants and animals require constant attention. Insecticides, herbicides, cultivation, and irrigation are all used to aid the plants and animals we need to maintain our dominant food-producing position in the world. In effect, these plants are able to live only under conditions that people carefully maintain. Furthermore, we plant vast expanses of the same plant, creating tremendous potential for extensive crop loss from diseases.

Whether we are talking about a clone or a hybrid population, there is the danger of the environment changing and affecting the population. Because these organisms are so similar, most of them will be affected in the same way. If the environmental change is a new variety of disease to which the organism is susceptible, the whole population may be killed or severely damaged. Because new diseases do come along, plant and animal breeders are constantly developing

Figure 11.8

Monoculture

This wheat field is an example of monoculture, a kind of agriculture in which large areas are exclusively planted with a single crop. Monoculture makes it possible to use large farm machinery, but it also creates conditions that can encourage the spread of disease.

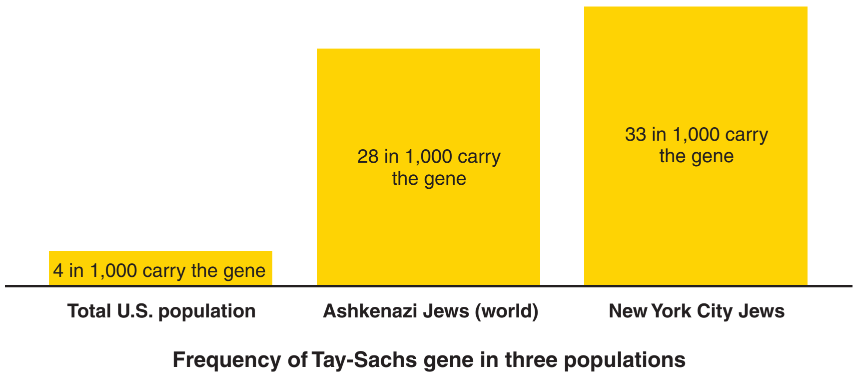


Figure 11.9

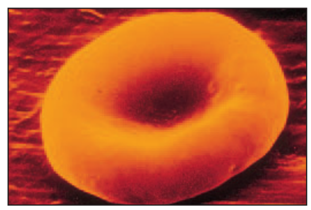
The Frequency of Tay-Sachs Gene
The frequency of a gene can vary from one population to another. Genetic counselors use this information to advise people of their chances of having specific genes and of passing them on to their children.

new clones, strains, or hybrids that are resistant to the new diseases. A related problem in plant and animal breeding is the tendency of heterozygous organisms to mate and reassemble new combinations of genes by chance from the original heterozygotes. Thus, hybrid organisms must be carefully managed to prevent the formation of gene combinations that would be unacceptable. Because most economically important animals cannot be propagated asexually, the development and maintenance of specific gene combinations in animals is a more difficult undertaking.

11.8 Human Population Genetics

At the beginning of this chapter, we pointed out that the human gene pool consists of a number of groups called *races*. The particular characteristics that set one race apart from another originated many thousands of years ago before travel was as common as it is today, and we still associate certain racial types with certain geographic areas. Although there is much more movement of people and a mixing of racial types today, people still tend to have children with others who are of the same social, racial, and economic background and who live in the same locality.

This non-random mate selection can sometimes bring together two individuals who have genes that are relatively rare. Information about human gene frequencies within specific subpopulations can be very important to people who wish to know the probability of having children with particular harmful combinations of genes. This is particularly common if both individuals are descended from a common ancestral tribal, ethnic, or religious group. For example, Tay-Sachs disease causes degeneration of the nervous system and early death of children. Because it is caused by a recessive gene, both parents must pass the gene to their child in order for the child to have the disease. By knowing the frequency of the gene in the background of both parents, we can determine the probability of their having a child with this disease.



(a)

(b)

Figure 11.10

Normal and Sickle-Shaped Cells
Sickle-cell anemia is caused by a recessive allele that changes one amino acid in the structure of the oxygen-carrying hemoglobin molecule within red blood cells. (*a*) Normal cells are disk shaped. (*b*) The abnormal hemoglobin molecules tend to stick to one another and distort the shape of the cell when the cells are deprived of oxygen.

Ashkenazi Jews have a higher frequency of this recessive gene than do people of any other group of racial or social origin and the Jewish population of New York City have a slightly higher frequency of this gene than the worldwide population of Ashkenazi Jews (figure 11.9). Therefore people of this particular background should be aware of the probability that they may have children who will develop Tay-Sachs disease.

Likewise, sickle-cell anemia is more common in people of specific African ancestry than in any other human subgroup (figure 11.10). Because many black slaves came from regions where sickle-cell anemia is common, African Americans should be aware that they might be carrying the gene for this type of defective hemoglobin. If they carry the gene, they should consider their chances of having children with this disease. These and other cases make it very important that trained **genetic counselors** have information about the frequencies of genes in specific human ethnic groups so that they can help couples with genetic questions.

11.9 Ethics and Human Genetics

Misunderstanding the principles of heredity has resulted in bad public policy. Often when there is misunderstanding there is mistrust. Even today, many prejudices against certain genetic conditions persist.

Modern genetics had its start in 1900 with the rediscovery of the fundamental laws of inheritance proposed by Mendel. For the next 40 or 50 years, this rather simple understanding of genetics resulted in unreasonable expectations on the part of both scientists and laypeople. People generally assumed that much of what a person was in terms of structure, intelligence, and behavior was inherited. This led to the passage of **eugenics laws.** Their basic purpose was to eliminate "bad" genes from the human gene pool and encourage "good" gene combinations. These laws often prevented the marriage or permitted the sterilization of people who were "known" to have "bad" genes (figure 11.11). Often these laws were thought to save money because sterilization would prevent the birth of future "defectives" and, therefore, would reduce the need for expensive mental institutions or prisons. These laws were also used by people to legitimize racism and promote prejudice.

The writers of eugenics laws (How Science Works 11.2) overestimated the importance of genes and underestimated the significance of such environmental factors as disease and poor nutrition. They also overlooked the fact that many genetic abnormalities are caused by recessive genes. In most cases, the negative effects of these "bad" genes can be recognized only in homozygous individuals. Removing only the homozygous individuals from the gene pool would have little influence on the frequency of the "bad" genes in the population. Many "bad" genes would be masked by dominant alleles in heterozygous individuals, and these genes would continue to show up in future generations. In addition, we now know that most characteristics are not inherited in a simple dominant/recessive fashion and that often many genes cooperate in the production of a phenotypic characteristic.

Today, genetic diseases and the degree to which behavioral characteristics and intelligence are inherited are still important social and political issues. The emphasis, however, is on determining the specific method of inheritance or the specific biochemical pathways that result in what we currently label as insanity, lack of intelligence, or antisocial behavior. Although progress is slow, several genetic abnormalities have been "cured," or at least made tolerable, by medicines or control of the diet. For example, phenylketonuria (PKU) is a genetic disease caused by an abnormal biochemical pathway. If children with this condition are allowed to eat foods containing the amino acid phenylalanine, they will become mentally retarded. However, if the amino acid phenylalanine is excluded from the diet, and certain other dietary adjustments are made, the person will develop normally. NutraSweet is a phenylalanine-based sweetener, so people with this genetic disorder must use caution when buying products that contain it. This abnormality can be diagnosed very easily by testing the urine of newborn infants.

Effective genetic counseling has become the preferred method of dealing with genetic abnormalities. A person known to be a carrier of a "bad" gene can be told the likelihood of passing that characteristic on to the next generation before deciding whether or not to have children. In addition, *amniocentesis* (a medical procedure that samples amniotic fluid) and other tests make it possible to diagnose some genetic abnormalities early in pregnancy. If an abnormality is diagnosed, an abortion can be performed. Because abortion is unacceptable to some people, the counseling process must include a discussion of the facts about an abortion and the alternatives. It is inappropriate for counselors to be advocates; their role is to provide information that better allows individuals to make the best decisions possible for them.

720.301 Sterilization of mental defectives; statement of policy

Sec. 1. It is hereby declared to be the policy of the state to prevent the procreation and increase in number of feeble-minded and insane persons, idiots, imbeciles, moral degenerates and sexual perverts, likely to become a menace to society or wards of the state. The provisions of this act are to be liberally construed to accomplish this purpose. As amended 1962, No. 160, § 1, Eff. March 28,1963.

Figure 11.11

A Eugenics Law

This particular state law was enacted in 1929 and is typical of many such laws passed during the 1920s and 1930s. A basic assumption of this law is that the conditions listed are inheritable; therefore, the sterilization of affected persons would decrease the frequency of these conditions. Prior to 1962, the law also included epileptics. The law was repealed in 1974.

HOW SCIENCE WORKS 11.2

Bad Science: A Brief History of the Eugenics Movement

- **1885** Francis Galton, cousin to Charles Darwin, proposes that human society could be improved "through better breeding." The term "eugenics" is coined; that is, "the systematic elimination of undesirables to improve humanity." This would be accomplished by breeding those with "desirable" traits and preventing reproduction of those with "undesirable" traits. John Humphrey Noyes, an American sexual libertarian, molds the eugenics concept to justify polygamy. "While the good man will be limited by his conscience to what the law allows, the bad man, free from moral check, will distribute his seed beyond the legal limit."
- **1907** The state of Indiana is the first to pass an involuntary sterilization law.
- **1919** Charles B. Davenport, founder of Cold Springs Harbor Laboratory and of the Eugenics Record Office, "proved" that "pauperism" was inherited. Also "proved that being a naval officer is an inherited trait." He noted that the lack of women in the navy also "proved" that the gene was unique to males.
- **1920** Davenport founds the American Eugenics Society. He sponsored "Fitter Families Contests" held at many state fairs around the country. The society persuaded 20 state governments to authorize the sterilization of men and women in prisons and mental hospitals. The society also put pressure on the federal government to restrict the immigration of "undesirable" races into the United States.
- **1927** Oliver Wendel Holmes argued for the involuntary sterilization of Carrie S. Buck. The 18-year-old Carrie was a resident of the Virginia State Colony for Epileptics and Feeble-Minded and the first person to be selected for sterilization under the law. Holmes won his case and Carrie was sterilized even though it was later revealed that neither she nor her illegitimate daughter, Vivian, were feebleminded.
- **1931** Involuntary sterilization measures were passed by 30 states.
- **1933–1941** Nazi death camps with the mass murder of Jews, Gypsies, Poles, and Russians were established and run resulting in the extermination of millions of people. "Adolf Hitler . . . guided by the nation's anthropologists, eugenists and social philosophers, has been able to construct a comprehensive racial policy of population development and improvement. . . . It sets a pattern. . . . These ideas have met stout opposition in the Rousseauian social philosophy . . . which bases . . . its whole social and political theory upon the patent fallacy of human equality. . . . Racial consanguinity occurs only through endogamous mating or interbreeding within racial stock . . . conditions under which racial groups of distinctly superior hereditary qualities . . . have emerged." (*The New York Times*, August 29, 1935)
- **1972–1973** Up to 4,000 sterilizations still performed in the state of Virginia alone, and the federal government estimated that 25,000 adults were sterilized nationwide.
- **1973** Since March 1973 the American Eugenics Society has called itself The Society for the Study of Social Biology.
- **1987** Eugenic sterilization of institutionalized retarded persons was still permissible in 19 states, but the laws were rarely carried out. Some states enact laws that forbid sterilization of people in state institutions.
- **Present** Some groups and individuals still hold to the concepts of eugenics claiming recent evidence "proves" that traits such as alcoholism, homosexuality, and schizophrenia are genetic and therefore should be eliminated from the population to "improve humanity." However, the movement lacks the organization and legal basis it held in the past. Modern genetic advances such as genetic engineering techniques and the mapping of the human genome provide the possibility of identifying individuals with specific genetic defects. Questions about who should have access to such information and how it could be used causes renewed interest in the eugenics debate.

SUMMARY

All organisms with similar genetic information and the potential to reproduce are members of the same species. A species usually consists of several local groups of individuals known as populations. Groups of interbreeding organisms are members of a gene pool. Although individuals are limited in the number of alleles they can contain, within the population there may be many different kinds of alleles for a trait. Subpopulations may have different gene frequencies from one another.

Genetically distinct populations exist because local conditions may demand certain characteristics, founding populations may have had unrepresentative gene frequencies, and barriers may prevent free flow of genes from one locality to another. These are often known as subspecies, varieties, strains, breeds, or races.

Genetic variety is generated by mutations, which can introduce new genes; sexual reproduction, which can generate new gene combinations; and migration, which can subtract genes from or add genes to a local population. The size of the population is also important, because small populations typically have reduced genetic variety.

Knowledge of population genetics is useful for plant and animal breeders and for people who specialize in genetic counseling. The genetic variety of domesticated plants and animals has been reduced as a result of striving to produce high frequencies of valuable genes. Clones and hybrids are examples. Understanding gene frequencies and how they differ in various populations sheds light on why certain genes are common in some human populations. Such understanding is also valuable in counseling members of populations with high frequencies of genes that are relatively rare.

THINKING CRITICALLY

Albinism is a condition caused by a recessive allele that prevents the development of pigment in the skin and other parts of the body. Albinos need to protect their skin and eyes from sunlight. The allele has a frequency of about 0.00005. What is the likelihood that both members of a couple would carry the gene? Why might two cousins or two members of a small tribe be more likely to have the gene than two nonrelatives from a larger population? If an island population has its first albino baby in history, why might it have suddenly appeared? Would it be possible to eliminate this gene from the human population? Would it be desirable to do so?

CONCEPT MAP TERMINOLOGY

Construct a concept map to show relationships among the following concepts.

allele frequency
breed
clone
genus
hybrid
monoculture
population
species

KEY TERMS

allele frequency
biological species concept
clones
eugenics laws
founder effect
gene frequency
gene pool
genetic bottleneck
genetic counselor
genetic diversity
hybrid
monoculture
morphological species concept
population
species
subspecies (races, breeds, strains, or varieties)

e—LEARNING CONNECTIONS *www.mhhe.com/enger10*

Topics	Questions	Media Resources
11.1 Populations and Species	1. How do the concepts of species and genetically distinct populations differ?	**Quick Overview** • Defining popluation **Key Points** • Populations and species
11.2 The Species Problem		**Quick Overview** • Defining species **Key Points** • The species problem
11.3 The Gene Pool Concept	2. Give an example of a gene pool containing a number of separate populations.	**Quick Overview** • Gene pools **Key Points** • The gene pool concept **Interactive Concept Maps** • Gene pools
11.4 Describing Genetic Diversity	3. What is meant by the terms gene frequency and allele frequency?	**Quick Overview** • Allele frequency **Key Points** • Describing genetic diversity
11.5 Why Genetically Distinct Populations Exist	4. Why do races or subspecies develop?	**Quick Overview** • Genetically distinct populations **Key Points** • Why genetically distinct populations exist

(*continued*)

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Topics	Questions	Media Resources
11.6 How Genetic Diversity Comes About	5. How does the size of a population affect the gene pool? 6. List three factors that change allele frequencies in a population.	**Quick Overview** • Genetic diversity **Key Points** • How genetic diversity comes about **Interactive Concept Maps** • Creating diversity
11.7 Genetic Variety in Domesticated Plants and Animals	7. How do the gene combinations in clones and sexually reproducing populations differ? 8. How is a clone developed? What are its benefits and drawbacks? 9. How is a hybrid formed? What are its benefits and drawbacks?	**Quick Overview** • Clones and monocultures **Key Points** • Genetic variety in domesticated plants and animals **Interactive Concept Maps** • Text concept map **Food for Thought** • Cloning
11.8 Human Population Genetics		**Quick Overview** • Knowing your genetic background **Key Points** • Human population genetics
11.9 Ethics and Human Genetics	10. What forces maintain racial differences in the human gene pool?	**Quick Overview** • Eugenics **Key Points** • Ethics and human genetics **Experience This!** • Eugenics where you live **Review Questions** • Diversity within species