7.1 Biological Change over Time

Figure 1 Snowshoe hares have evolved a number of adaptations that allow them to survive in winter.

Everywhere we look we see change. We live on a dynamic Earth that we share with millions of other species, comprising trillions of individual organisms. We observe life changing over time—individuals grow and mature and new generations come and go. The physical Earth also changes. Some changes are rapid, while others are slow and may go unnoticed. For example, you can observe a forest fire or the birth of a baby, but the changes that occur during ecological succession after a fire, and the changes that occur as a baby grows, are too slow to be seen on a day-by-day basis. The slower and more gradual the change, the more difficult it is to observe and investigate.

As you learned in the Diversity of Living Things unit, biologists are convinced that entire species change over time—they evolve. For example, over time snowshoe hares have evolved a number of adaptations that improve their survival in cold snowy winters. Their coat changes from brown to white for the winter and they have unusually wide feet for moving on deep soft snow (**Figure 1**). How do biologists detect such evolutionary changes in species, and what causes them to occur? How might the environment influence evolutionary changes in species?

Mutations: The Source of Genetic Variation

All species, including humans, exhibit genetic variation. The original sources of genetic variation are mutations, which are changes in genetic information. Mutations create new genes that provide a continual supply of new genetic information. Mutations that enter populations have an immediate and direct effect on individuals and also have the potential to influence future generations when those mutations are inherited.

Mutations may be neutral, harmful, or beneficial. Most mutations are neutral and result in changes in DNA that have no immediate effect. **Neutral mutations** are those that provide no benefit or harm to the individual. **Harmful mutations** reduce the reproductive success of an organism. Examples of harmful mutations include those that lead to serious genetic disorders such as cystic fibrosis or Huntington's disease. **Beneficial mutations** produce a change in an individual's phenotype that gives the individual an advantage. Beneficial mutations give individuals a better chance of survival in their environment. For example, the sickle-cell allele gives carriers a high degree of resistance to malaria and dramatically enhances their chances of survival in regions where malaria is endemic.

neutral mutation a mutation that does not result in any selective advantage or disadvantage

harmful mutation any mutation that reduces the reproductive success of an individual and is therefore selected against; harmful mutations do not accumulate over time

beneficial mutation any mutation that increases the reproductive success of an organism; beneficial mutations are favoured by natural selection and accumulate over time

The changes that arise in species through mutation can have significant consequences. Bacteria that have developed resistance to antibiotics are becoming more widespread as less-resistant strains are killed off (**Figure 2(a)**). Similarly, insect and other pest species that have developed resistance to various pesticides are becoming more common and difficult to control (**Figure 2(b)**). From the perspective of harmful bacteria or other pest species, any mutations that confer increased resistance are beneficial. Humans, however, would consider these mutations undesirable.

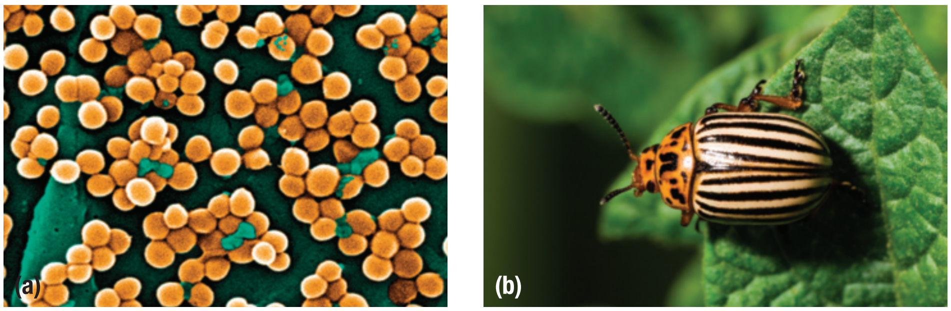

Figure 2 There is growing concern over the ability of disease-causing bacteria, such as (a) methicillin-resistant *Staphylococcus aureus* (MSRA), and insect pests, such as (b) the Colorado potato beetle, to evolve resistance to the antibiotics and insecticides we use to control them.

Some mutations have serious consequences for human health. For example, viruses, like living cells, carry genetic information that can undergo mutation. This means that populations of disease-causing viruses, such as the human influenza virus, are genetically variable and change over time. In rare instances, a mutation may increase the virulence of a virus or enhance its ability to spread. The result can be a deadly epidemic. Each year the World Health Organization and other health agencies try to predict which virus strains pose the greatest threat to humans and then work to develop an effective flu vaccine (**Figure 3**).

The most obvious changes to species are those that have occurred in domesticated species of plants and animals. In most cases, unmodified members of the original species still remain in the wild, but in other cases, such as that of certain breeds of domesticated cattle, the original species is now extinct. Changes that have occurred during domestication are a direct result of human manipulation.

Figure 3 Each year millions of Ontarians receive the seasonal flu shot. A new vaccine is needed each year because the influenza virus is continuously changing.

Selective Breeding: Artificial Selection of Traits

The domestication of animals and plants is one of the most important technological innovations in human history. Domesticated plants and animals provide humans with the vast majority of our food supply and formed the basis for the development of modern civilizations.

Domestication is the changing of members of a species to suit human needs through controlled captive breeding. The controlled captive breeding process is referred to as **artificial selection**—*artificial* because it occurs in captivity rather than in a natural setting and *selection* because humans choose which specific animals or plants are bred. The breeder selects individuals that exhibit a desired trait or traits and uses these individuals as the parents of the next generation.

Humans have been domesticating animals and plants for more than 10 000 years. You might be surprised to learn that the earliest animal to be domesticated was *Canis lupus*, the wolf (**Figure 4**). Of course we no longer refer to the domesticated variety as wolves, but rather as dogs. Genetic information provides compelling evidence that all modern breeds of dogs are descended from wolves (**Figure 5**). For this reason, dogs are considered a subspecies of wolves and have been given the scientific name *Canis lupus familiaris*.

artificial selection directed breeding in which individuals that exhibit a particular trait are chosen as parents of the next generation; artificial selection is used to produce new breeds or varieties of plants and animals

Figure 4 The wolf, *Canis lupus*, is the ancestral species of all modern dog breeds.

Figure 5 Thousands of years of artificial selection have produced a great variety of dog breeds. During this time a single mutation is thought to have produced a dog with achondroplasia—a form of dwarfism. The descendents of this dog have since given rise to bassets and dachshunds.

Plants are equally capable of being selectively bred to suit our needs. For example, several thousand years of domestication of the wild sea cabbage, *Brassica oleracea*, have produced a wide array of vegetables (**Figure 6**). These diverse vegetables are, in fact, altered forms of the same original species. Differences in taste and appearance are the result of artificial selection acting over thousands of generations.

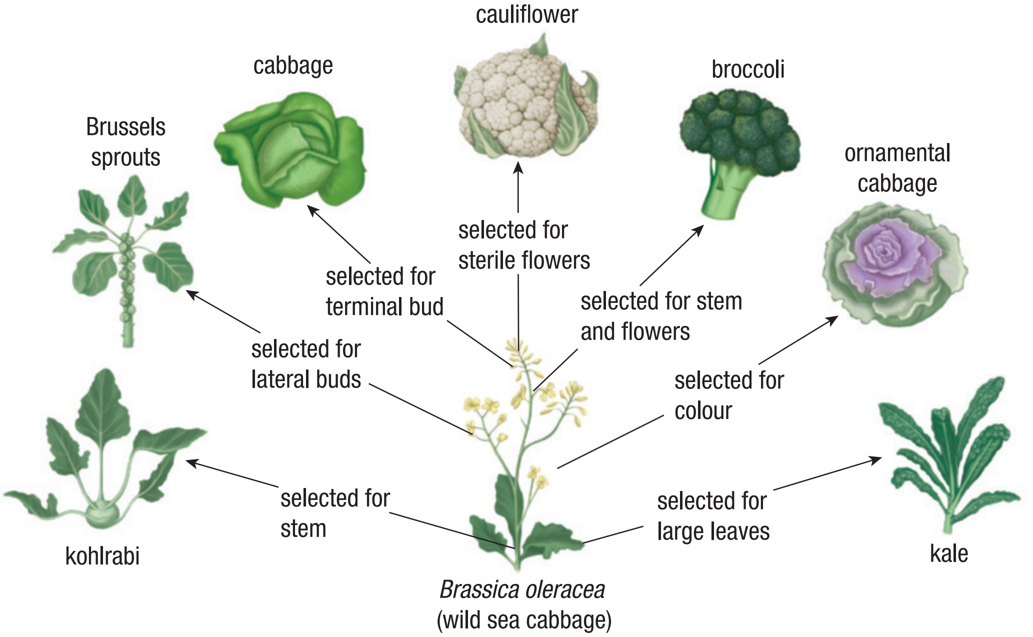

Figure 6 These seven well-known plants are domesticated varieties of the wild sea cabbage.

How does artificial selection work? How can animal and plant breeders turn wolves into Chihuahuas and St. Bernards, and wild cabbage into broccoli and kohlrabi? The process is surprisingly simple but, with the exception of modern genetic engineering techniques, very slow. The breeder usually has a particular feature in mind. For example, the Aboriginal peoples of Mesoamerica domesticated the tomato. Wild tomato plants produce nutritious but small fruit (**Figure 7**). As with any species, these plants exhibited variability—some were a little larger than others, some produced larger fruits, and some tasted better than others. Generation after generation, farmers selected seeds from the best plants to sow the next season. The seeds germinated, grew, flowered, and then cross-pollinated one another, producing more fruit with the desired traits. The farmers consumed most of the fruit as food but carefully examined the plants and saved seeds from the very best plants for sowing. These practices happened in many parts of the world (**Table 1**).

Table 1 Domesticated Species and Their Areas of Origin

Region	Domesticated species
Eurasia	apple, grape, dog, goat, horse
North and South America	peanut, potato, sunflower, llama
Africa	sorghum, Guineafowl

Figure 7 Beginning with (a) a wild species of tomato, farmers chose only those plants that exhibited the most desirable traits as a source of seeds for the next generation of planting. The result of thousands of generations is (b) the modern tomato.

The Science of Breeding

Most traditional animal and plant breeders would not consider themselves scientists, but what they do is often equivalent to a tightly controlled experiment. Each time breeders attempt to develop a new breed, they are testing a hypothesis and following a common set of procedures:

Hypothesis: Breeding selected individuals with certain favoured traits will result in the favoured traits becoming more prevalent and more pronounced.

Independent variable: breeding population (selected by the breeder)

Dependent variable: appearance of favoured trait in the population

Procedure:

1. Choose a useful species that can be bred in captivity.
2. Breed a large number of individuals.
3. Choose a trait that you wish to favour, such as large size, a particular colour, or sweetness.
4. Identify individuals that exhibit the favoured trait most strongly.
5. Breed only these individuals to produce the next generation of individuals.
6. Repeat Steps 4 and 5 over many generations.

In most cases the hypothesis is confirmed. The favoured trait becomes widespread throughout the population and also becomes enhanced. What early breeders likely did not expect was the degree to which the populations would change.

Modern breeding, particularly of crop plants, has undergone a revolution. Today scientists routinely use genetic engineering techniques to transfer what they hope will be beneficial genes from an individual of one species to an individual of another species. When successful, the genetically modified individual is often mass-produced by cloning. This practice can result in the widespread use of genetically modified plants with little or no genetic diversity. Although the pros and cons of genetic engineering are hotly debated, one thing is certain: these genes have all arisen in natural populations, and a loss in biodiversity also results in a loss of potentially valuable genes.

The Power of Artificial Selection

The most unexpected result of artificial selection is the production of individuals that exhibit traits that are far beyond the natural variability witnessed in the original breeding population. Adult Chihuahuas are not simply small wolves; they are much smaller than even the smallest of adult wild wolves, and they look very different. Giant red tomatoes can be a hundred times as large as the largest wild tomato fruit. Looking back to the traits of the first wild plants and animals used for breeding, no one could have imagined the power of selective breeding (**Figure 8**).

Figure 8 Artificial selection can produce surprising results, such as (a) this giant pumpkin or (b) the long horns of this Texas Longhorn.

Artificial selection methods can also reduce genetic diversity within a population. If breeders favour only certain traits within a population, then the many alleles linked to other versions of a particular characteristic are reduced or eliminated. Such a loss in diversity makes a population more vulnerable to disease. For example, large cobs of sweet corn might be favoured by plant breeders but might also be favoured by insect pests. In addition, some favoured traits can be linked to alleles that are detrimental. For example, some breeds of dogs are more prone to genetic disorders such as hip dysplasia and cancer because the alleles associated with these disorders are inherited along with the alleles that produce the favoured traits of those particular breeds.

THE 100 YEAR EXPERIMENT

The longest-running formal experiment in artificial selection is being conducted by the Illinois Agricultural Experiment Station. The experiment began in 1896 and is still under way. The purpose of the experiment was to test the effect of artificial selection on the oil content of corn seeds. The design involved two separate breeding experiments. In the first, corn plants were selected for high oil content, whereas in the second they were selected for low oil content. Over 76 years, the oil content increased from 5 % to more than 18 % in the first experiment, while it dropped to less than 1 % in the second (**Figure 9**). This evidence proves that the process of artificial selection can indeed be used to dramatically increase or decrease oil content in corn seeds.

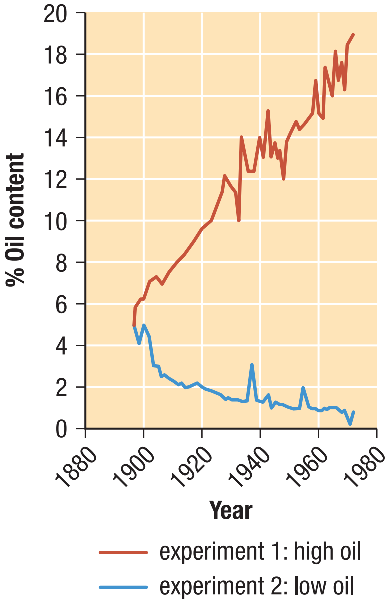

Figure 9 Artificial selection can increase or decrease the oil content in corn.

LIMITATIONS OF ARTIFICIAL SELECTION: THE INFLUENCE OF MUTATIONS

Not all attempts at artificial selection have been successful. Breeders cannot create traits that do not already exist in some form within the population. If there are no genes for blue roses (long sought after by flower lovers), then no amount of crossbreeding will create one. Breeders must work with the genetic diversity that already exists in the population or resort to genetic engineering technology to alter it. This does not mean that new mutations cannot arise, however, and when this happens the breeder has new material with which to work. There is always room for hope that someday a mutation will occur that gives rise to a truly blue rose.

Beneficial or neutral mutations have a good chance of being passed on to future generations because they are either favoured or go unnoticed. In contrast, mutations that cause harm, or produce an undesirable trait in an individual, have little influence on the potential success of artificial selection efforts. Breeders simply do not choose such individuals for breeding, and therefore the harmful mutations are not passed on to the next generation. In rare circumstances, however, an undesirable trait may accompany a beneficial one. An interesting example has occurred in the breeding of strawberries. Ontario breeders routinely attempt to develop plants that are more tolerant of cold. This would allow the plants to be grown farther north. Unfortunately, while the breeding programs have produced a number of strawberry plants that are quite hardy, these plants produced berries that are white on the inside. The breeding of these plant varieties was discontinued based on the expectation that consumers would not be willing to buy these odd-coloured berries.

CAREER **LINK**

Animal or Plant Breeder
Animal or plant breeders select individuals with desirable traits and breed them. To learn more about becoming an animal or plant breeder,

GO TO NELSON SCIENCE

UNIT TASK **BOOKMARK**

Consider how you can apply an understanding of genetic changes and selection as you work on your Unit Task.

Implications for Natural Populations

How can we apply our current understanding about genetics and artificial selection to the millions of species that exist in the wild? We should first recap what we already know about genetics:

- All species exhibit genetic variation.
- Mutations produce heritable changes in individuals, and these changes may be beneficial, harmful, or neutral.
- Some species, such as bacteria and insects, can change over relatively short periods of time.
- Some domesticated species have changed dramatically under the influence of artificial selection.

These observations are based on a large number of species that have been domesticated over relatively short periods of time—at most over several thousand years. How, then, might similar processes influence the populations of all species on Earth? If we can begin with a population of wolves and change them into hundreds of distinct breeds of dog, what might happen to a species over thousands or millions of years living under natural conditions?

One of the challenges faced by biologists trying to answer these questions is how and where to obtain useful evidence. You can imagine that one of the most useful places for biologists to look would be back in time. Biologists do not have time machines, but fortunately Earth keeps some records of the history of life (**Figure 10**).

Figure 10 The Grand Canyon was formed by erosion. The Colorado River has cut through and exposed sedimentary deposits that are hundreds of millions of years old.

7.1 Summary

- Mutations create new genetic information and add genetic diversity to species.
- Beneficial mutations can have significant positive consequences for species.
- Artificial selection is a process in which individuals with particular favoured traits in each generation are chosen as the breeding stock for the next generation.
- When practised over many generations, artificial selection can produce dramatic changes in the traits of a population.
- Artificial selection is limited by the genetic variability within the breeding population.
- Artificial selection methods can reduce the overall genetic diversity of the population and therefore contribute to the loss of biodiversity.

7.1 Questions

1. The chances of any one individual being born with a beneficial mutation is very low. How then is it possible for mutations to play such a key role in evolution? K/U
2. How might it be possible for a neutral mutation to play an important role in the evolution of a species? K/U
3. Explain why harmful mutations do not accumulate over time and cause harm to populations. K/U
4. Use the evolution of antibiotic resistance to show how a mutation that is advantageous for one species can be harmful for another. K/U
5. Most wolves look quite similar. Use the domestication of dogs to illustrate the genetic diversity that is contained within the wolf population. K/U
6. All domestications of plants and animals begin with humans selecting a wild species living nearby. Use the Internet and other sources to research where each of the following domesticated species originated: T/I A
   (a) chicken
   (b) pig
   (c) cattle
   (d) corn
   (e) wheat
   (f) rice
   (g) chocolate
   (h) coffee
   (i) squash
7. Using a specific example, outline a hypothesis and simple step-by-step procedure a breeder could use to create a breed with a desired trait. K/U A
8. How have modern genetic engineering methods changed the way that plant breeders develop plants with new and potentially valuable traits? K/U
9. How do the genetic diversity of a population and mutation rates limit the ability of breeders to create organisms with desired traits? K/U A
10. In 1975, Japanese scientists discovered bacteria feeding on nylon in a chemical waste water pond. Nylon is a synthetic compound that was invented in 1935. Do online research to find out how mutations are thought to have produced this "nylon bug." Also learn how scientists have induced other bacteria to evolve the ability to feed on nylon. T/I
11. The discovery of the mutation responsible for the short legs of certain dog breeds was made by scientists at the National Human Genome Research Institute. Use the Internet and other sources to find out the following: T/I
    (a) Why were human geneticists interested in this dog trait?
    (b) How did the scientists conduct their study? How many dogs did they investigate?
    (c) What type of genetic change was responsible for this form of dwarfism?

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