SBI3U-C

Lesson 2

Natural Selection and Evidence for Evolution

Introduction

Darwin called his mechanism for evolution natural selection, sometimes known as "survival of the fittest." In this lesson, you will learn about the process of natural selection and the evidence Darwin used to support his theory. You will also explore how human activities are changing the environment of the planet in ways that affect the direction and rate of evolution of all species, including endangered ones. You will see how artificial selection has both positive and negative impacts. Finally, you will evaluate the risks and benefits of a new type of artificial selection: the genetic modification of species, especially food crops and livestock.

Planning Your Study

You may find this time grid helpful in planning when and how you will work through this lesson.

Suggested Timing for This Lesson (hours)	
Evolution by Natural Selection	½
Evidence for Evolution by Natural Selection	1½
Human Impacts on Evolution	1
Key Questions	1

What You Will Learn

After completing this lesson, you will be able to

- evaluate the possible impact of an environmental change on natural selection and on the vulnerability of species
- use appropriate terminology related to evolution
- explain the fundamental theory of evolution, using the evolutionary mechanism of natural selection to illustrate the process of biological change over time
- explain the process of adaptation of individual organisms to their environment
- analyze the economic and environmental advantages and disadvantages of an artificial selection technology, and evaluate the impact of environmental changes on natural selection and endangered species
- investigate evolutionary processes and analyze scientific evidence that supports the theory of evolution

Evolution by Natural Selection

Evolution simply means change over time. The fossil record, as well as our own success at breeding domestic animals and crops, shows that species can evolve new traits and even become new species. The big question is how this evolution happens.

Evolution occurs at the population level. Individual organisms do not "evolve" over their lifetime because their genetics do not change. But the amounts of different genetic types (genotypes) within a population do change over time, sometimes enough to create a new species. This happens because there is genetic variation in all populations. Some individuals are very successful at surviving and finding resources, and can therefore produce many offspring who share the same genotype as their parent. Others are not as successful and produce fewer offspring. Eventually, the genotypes of the successful individuals tend to become dominant within the population; they have been "selected" by nature to survive and reproduce.

In Figure 2.1, below, a normal-coloured plant can mutate to produce either lighter-coloured plants or darker-coloured plants. If the environement is more favourable to the darker-coloured plants, then the lighter-coloured ones will eventually die off. This could happen, for example, if there were an animal that could see the lighter plants better and therefore ate them more often, leaving the darker ones alone. The darker plants would survive longer and could reproduce, making more darker-coloured plants.

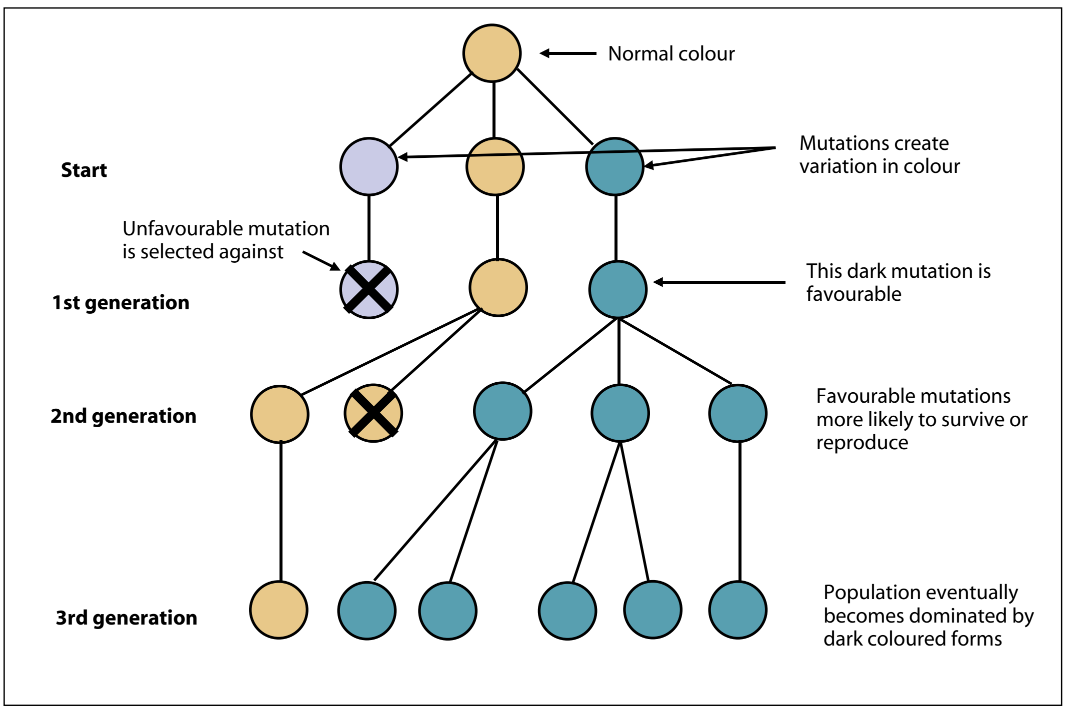


Figure 2.1: How natural selection results in a population dominated by a new type

Eventually, enough mutations are selected within the population to create a new species.

You will learn more about how this process works later in the lesson.

Darwin summarized natural selection in these words from his book *On the Origin of Species*:

> Can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and procreating their kind? On the other hand, we may feel sure that any variation in the least degree injurious would be rigidly destroyed. This preservation of favorable variations and the rejection of injurious variations, I call Natural Selection.

Importance of Evolution by Natural Selection

Natural selection is constantly occurring, and sometimes evolution can happen in a very short time. For example, natural selection of antibiotic-resistant bacteria is leading to untreatable diseases. Researchers are in a race against evolution to find drugs to fight these bacteria before they can evolve new defenses.

Natural ecosystems are always evolving too. This evolution is necessary to help them adapt to environmental stress. For example, recent research shows that new species originate 50% faster in coral reefs than in other habitats. Unfortunately, due to excessive amounts of carbon dioxide in our atmosphere, the oceans are heating up and becoming more acidic. The coral reefs are dying because of the increased heat and lower pH of the water. If coral reefs die off, the ocean will gradually lose the ability to create new species by evolutionary processes.

Knowledge of evolution and natural selection is also important for our economies as we struggle to find enough food to feed our growing global population. Understanding how evolution works on the genetic code is helping us create new varieties of crops able to grow in poor soils, and design new drugs using rapidly-evolving bacteria as a laboratory.

Figure 2.2: Photograph of a coral reef with many different species

Source: Wikipedia

Conditions Needed for Evolution by Natural Selection to Occur

Darwin's theory of evolution by natural selection was based on three conditions, each of which was already understood—but no one had thought to connect them. Darwin showed that if all three conditions existed, evolution by natural selection was likely. The three conditions are:

1. Variation within the population
2. A struggle for existence: survival of the fittest
3. Descent with modification: the ability of survivors to pass their characteristics on to the next generation

1. Variation Within the Population

Individuals in natural populations vary extensively. There are differences in size and shape, behaviour, physiology and reproductive abilities. Each of these differences, no matter how small, could potentially affect an individual's survival or reproductive success. Animal breeders had recognized this fact for centuries, and used it to selectively breed only the best animals to improve their herds.

Figure 2.3: This image shows different hair colours. Hair colour is an example of variation in a population. There are many versions of the hair color gene, such as blond, red, brown, and black.

Source: Wikipedia

2. A Struggle for Existence

Darwin realized that high birth rates and a limited amount of life's basic needs (food, shelter) would eventually force organisms into a competition for resources. This struggle for existence meant that individuals within a species would regularly compete with each other to obtain food, living space, and other necessities—and not all of them would succeed.

A key factor in the struggle for existence, Darwin observed, was how well-suited an organism is to its environment. Darwin called the ability of an individual to survive and reproduce in its specific environment “fitness.” This should not be confused with physical fitness; an individual that is weak and slow relative to other members of its species could still have higher fitness if it was more successful at producing offspring (maybe because it was better at hiding from predators instead of trying to run away from them).

Darwin argued that the concept of fitness was central to the process of evolution by natural selection. Generation after generation, individuals compete to survive and produce offspring. The less successful individuals either die or leave fewer offspring. Individuals that are better suited to their environment are able to survive and produce more offspring, and are therefore said to have higher fitness. Darwin called this competitive process “survival of the fittest.”

Figure 2.4: Photograph of two different peppered moths on a tree. One is lighter in colour and the other is darker. The lighter one blends in, or camouflages, better against the tree bark, so predators can’t see it as well. As a result, the lighter one has a higher degree of fitness.

Source: Wikipedia

3. Descent with Modification

Fitter individuals leave more offspring. But evolution by natural selection can only occur if the fit individuals also pass their traits on to their offspring. The fitness must be heritable (able to be inherited). Darwin didn’t know exactly how this process worked, but he could see from animal breeding that offspring inherited features from their parents. Today we know that traits are inherited through an organism’s DNA.

Darwin proposed that fitness is a result of inherited adaptations. Successful adaptations, according to Darwin, enable organisms to become better suited to their environment and thus better able to survive and reproduce. Adaptations can be physical features, such as a longer neck on a giraffe, or more complex adaptations such as courtship behaviour.

Darwin postulated that, over long periods of time, natural selection produces organisms that have different structures, establish different niches, or occupy different habitats. As a result, species today appear different than their ancestors. Each living species has descended, with changes, from other species over time. He referred to this principle as "descent with modification."

Putting It All Together

Darwin's genius lay in the way he combined these three conditions to come up with his theory. Each piece had been known for some time. Farmers had always seen variation in their herds or crops, and naturalists had documented much variation in natural populations.

If all three conditions are present, evolution becomes possible. In fact, if all are present, it is very difficult to prevent evolution from occurring, as we have seen with the example of drug-resistant bacteria. Natural selection is a process that occurs without human intervention. Over time, it brings about changes in the inherited characteristics of a population, and can eventually lead to the formation of new species.

In the rest of this lesson, you will learn more about the process of natural selection, the evidence that supports it, and how humans can affect this natural process directly or indirectly.

Support Questions

Be sure to try the Support Questions on your own before looking at the suggested answers provided.

4. Some insects can survive the chemicals that farmers use on crops to kill them. Explain how resistance to pesticides by some insects is an example of evolution by natural selection. Suggested answer

5. What are the three conditions necessary for evolution by natural selection to occur? Suggested answer

6. Do you think evolution would occur if all the individuals in a population had the exact same genes? Explain. Suggested answer

Evidence for Evolution by Natural Selection

Many types of evidence indicate that evolution has occurred and that natural selection is the chief mechanism driving changes in the characteristics of species over time. You will examine six different types of evidence.

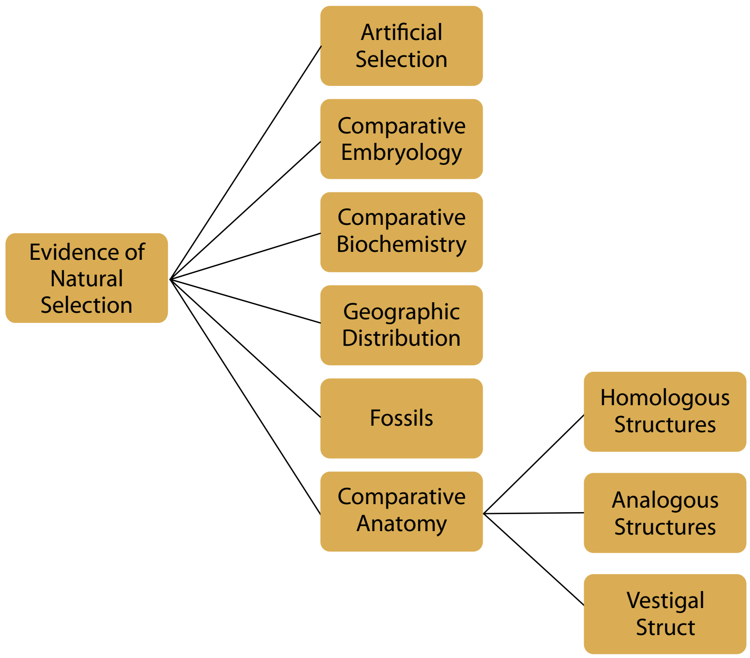


Figure 2.5: Diagram showing the different types of evidence for natural selection

1. Fossils

Darwin collected many fossils during his voyage on the *H.M.S. Beagle*. He began to view them as a detailed record of evolution.

Darwin noted that the fossils of ancient organisms are simpler in structure than present-day organisms. Sequences of fossils have been discovered that show a gradual series of changes in form as one progresses through layers of sediment or volcanic ash. The oldest fossils are in the deepest layers. Moving up through the layers (or strata), organisms become increasingly complex and recent. In some cases, examining fossils from sequential layers of rock, one could infer how a species had changed over time.

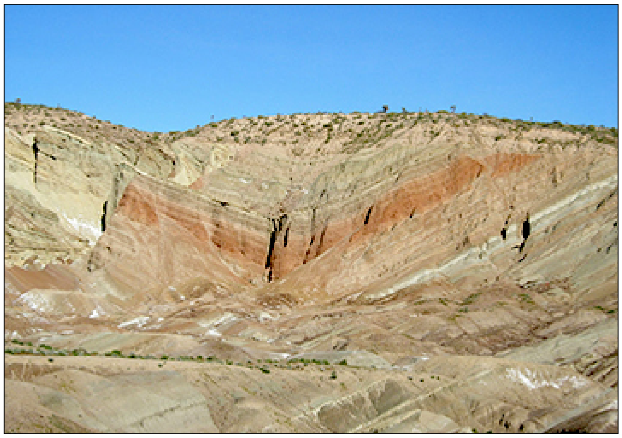


Figure 2.6: Photograph of the Rainbow Basin in California showing layers, or strata, of rock. The bottom layers would contain the oldest and simplest fossils. The top layers would contain the more recent and complex ones.

Source: Wikipedia

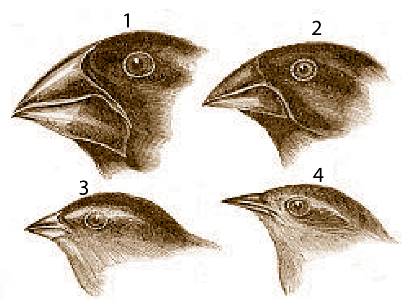
A famous example of a fossil collection is the Burgess Shale site in the Canadian Rockies. It contains the fossils of marine organisms that lived 500 million years ago. Canadian researchers at the Royal Ontario Museum have been collecting and studying fossils from this site since the 1970s. These fossils reveal life forms that are very different than those in existence today, indicating that great changes have occurred in the diversity of life since then.

Figure 2.7: Photograph of the quarry at the Burgess Shale site

Source: Wikipedia

2. Geographic Distribution of Living Species

Darwin collected many species of finches while visiting the Galapagos Islands. He wondered how the birds could show such strong adaptations to their individual, isolated environments yet still prove to be closely related species (Figure 2.8). He decided that all these birds could have descended with modifications from a common finch ancestor that arrived from South America.



1. Geospiza magnirostris 2. Geospiza fortis
3. Geospiza pannula 4. Certhidea olivacea

Finches from Galapagos Archipelago

Figure 2.8: Image of four species of Darwin's finches showing how different bill shapes evolved from a common ancestor. Each species adapted to eating certain kinds of food.

Source: Wikipedia

Darwin also noticed that totally unrelated species living on different continents, like Australia and South America, had very similar appearances or behaviours. Darwin postulated that this was because they faced similar environmental selection pressures, and therefore developed similar features. Examples include the wolf and the marsupial Tasmanian wolf, the flying squirrel and the marsupial flying phalanger, and the mouse and marsupial mouse. In each case, the two species are not closely related yet look remarkably alike and play similar ecological roles.

Figure 2.9: Photograph of a marsupial mouse from Australia, which looks like the common mouse found in Canada. However, the two animals are not closely related.
Source: Wikipedia

3. Comparative Anatomy

Organisms thought to be related through a common ancestor exhibit many similar anatomical structures. Anatomical structures can reveal evidence of evolution in three ways: through homologous, analogous, and vestigial structures.

i) Homologous Structures

Homologous structures are body parts that are shared between species because they share a common ancestor. These body parts may have different uses, but still have similar anatomy. Homologous structures provide evidence of descent with modification from a common ancestor. The more similar the homologous structures are, the more recent the common ancestor.

For example, pentadactyl or 5-finger forelimbs are present in vertebrates (organisms with a backbone), but have varying functions depending on the species (Figure 2.10). In apes, all five fingers are used for grasping and holding objects such as food, but in dogs, only four of the digits are used for walking and clawing. In cows, only two digits are used, and in horses, only one digit is used—the other four digits are still there, but have shrunk in size. This allows horses to run much faster.

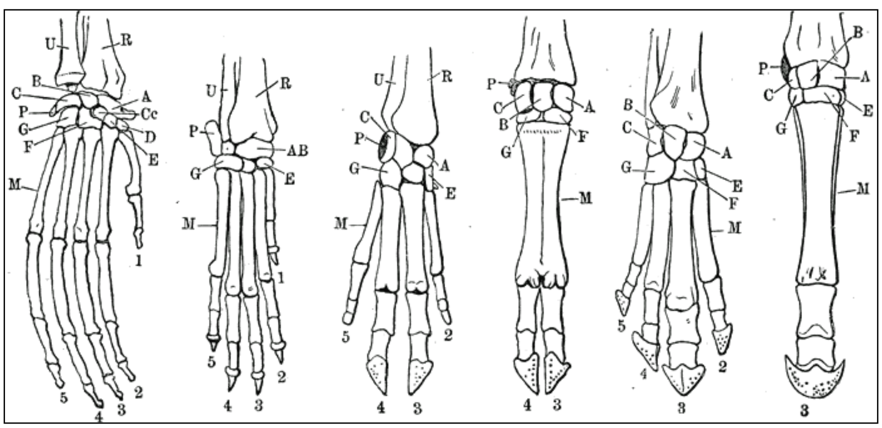


Figure 2.10: Image of six homologous structures. The forelimbs of these vertebrate organisms have similar bones, suggesting descent from a common ancestor. The species from left to right are: orangutan, dog, pig, cow, tapir, horse.

Source: Meyers Konversations-Lexikon

ii) Analogous Structures

Analogous structures are those that have similar functions and appearance, but have different anatomy. Examples include the wings of birds, bats and the extinct pterosaurs (Figure 2.11). The similarities are due to similar selective pressures, but do not demonstrate any recent common ancestry. In all three cases, the wings are used for flying, but they evolved independently using different parts of the forearm and materials (feathers versus skin flaps).

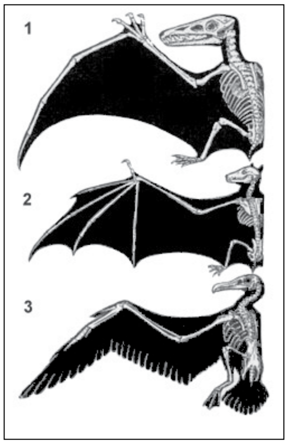


Figure 2.11: Image of three analogous structures. The wings of the pterosaur (1), bat (2) and bird (3) look similar but are made using different bones and materials. These species are not closely related.
Source: Wikipedia

Analogous structures like these wings do not show evolutionary relationships between organisms. However, they provide evidence for natural selection because species facing similar selection pressures possess similar adaptations.

Support Questions

7. Explain the difference between homologous structures and analogous structures.

Suggested answer

iii) Vestigial Structures

Vestigial structures are structures that have no current function but are homologous to functional structures in related organisms. For example, whales evolved from terrestrial four-legged ancestors. They still retain some evidence of their four-legged past because they have vestigial back legs that are not used for anything, but can be seen in their skeleton (Figure 2.12).

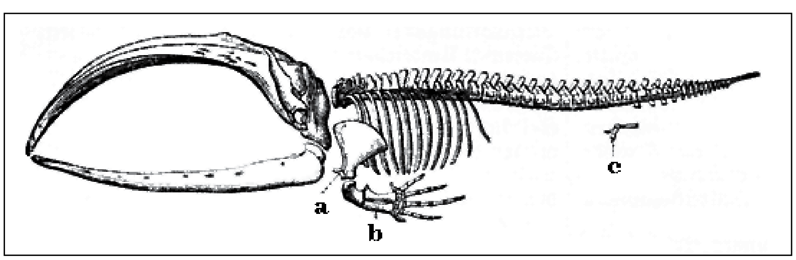


Figure 2.12: Image showing the vestigial back legs (labelled "c") in a baleen whale skeleton
Source: Wikimedia Commons

4. Comparative Embryology

Embryological studies also support the theory of evolution They study the early development of a fertilized egg. All vertebrate embryos proceed through very similar stages of development. This is because all vertebrate embryos inherited the same basic genetic plan for development from their shared ancestor millions of years ago. For example, fish, turtles, chickens, mice, and humans all develop tails and gill arches early in their development, even though only a few maintain these structures as adults. In general, the more similar the embryonic stages, the more closely the organisms are related. In Figure 2.13, notice the similarity between the embryonic stages of the calf and hog, which are closely related.

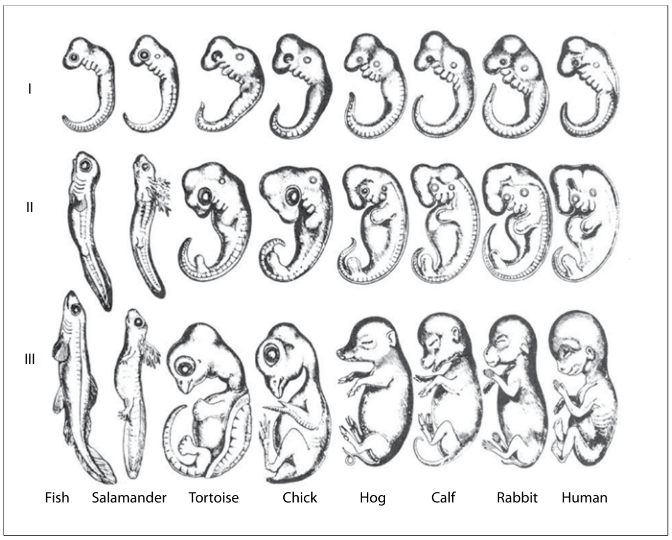


Figure 2.13: Image showing different types of vertebrate embryos, all with similar stages of development

Source: Wikimedia Commons

5. Comparative Biochemistry and Genetic Evidence

A recent development in evolutionary biology is the ability to measure genetic and biochemical similarities. Similarities in gene structure, protein structure and DNA all provide evidence of the descent of related species through evolution from common ancestors.

The genetic code is the ultimate link to ancestral species. As species evolve from a common ancestor, they gradually acquire slightly different genetic codes. The more distantly related they are to another species, the larger the difference in their genetic codes. Biologists therefore use genetic analysis to determine how closely species are related to one another. A famous example of this is the genetic analysis comparing humans to the great apes (gorillas, chimpanzees, and orangutans). Figure 2.14 shows a tree diagram summarizing the genetic relatedness among humans and the great apes. Notice that humans (Homo) are more closely related to chimpanzees (Pan) than they are to gorillas (Gorilla) and orangutans (Pongo). This indicates that humans and chimpanzees shared a common ancestor more recently.

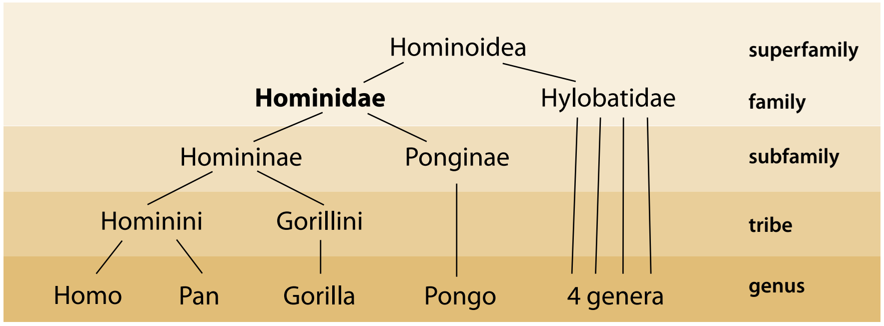


Figure 2.14: Tree diagram showing the degree of relatedness among the higher primates

Source: Wikimedia Commons

6. Artificial Selection

Rapid, heritable changes have been produced in domestic animals and plants by selectively breeding individuals with desired features. For example, the differences in dog breeds have only occurred over the past few thousand years. If differences as vast as those occurring between the tiny chihuahua and the huge Great Dane (Figure 2.15) can be produced in only a few thousand years of artificial selection by humans, it is not difficult to understand how much larger changes can occur over millions of years by natural selection.

Figure 2.15: Photograph of a chihuahua and a Great Dane, showing their difference in size

Source: Wikipedia

In the example of the chihuahua and the Great Dane, they both originated from a mid-sized dog thousands of years ago. Some people chose to breed the smallest of these mid-sized dogs, causing each generation to produce smaller and smaller dogs, eventually creating the chihuahua. Other people chose to breed the largest dogs, causing each generation to become larger and larger, eventually creating the Great Dane.

Example of Rapid Evolution: Industrial Melanism

Both natural and human activities may drastically change the environment over short periods of time. Significant changes in the characteristics of species have been observed in response to these environmental changes. A well-studied example is the evolution of black coloration (melanism) among peppered moths in England in response to the darkening of their environment by industrial pollutants (Figure 2.16).

Figure 2.16: Two forms of peppered moth, light and dark (melanic)
Source: Wikipedia

This darkening occurred during the Industrial Revolution in the 1800s. Prior to the Industrial Revolution, black moths were extremely rare as they stood out against the light bark of trees, making them easy prey for birds and other predators. However, with the Industrial Revolution came pollution from coal smoke that darkened the bark of trees. The darker moths increased in number as they now had the better camouflage and were invisible to predators. The once abundant white moths were suddenly very visible to predators against the dark tree trunks.

As pollution controls got better and the air quality improved, the amount of coal smoke in the atmosphere declined. Today, the bark of trees has returned to its original lighter colour, so the selection has turned against the dark moths and they are now rare again.

Support Questions

8. The theory of evolution by natural selection explains, in scientific terms, how organisms evolve over time. What is being selected in this process? Suggested answer

9. What types of evidence did Darwin use to support his theory of change over time? Suggested answer

10. Although wild turkeys can fly, domesticated (farmed) turkeys cannot. Explain how natural selection could have produced the non-flying domesticated turkeys. Suggested answer

Human Impact on Evolution

Darwin recognized the distinction between selection due to human intervention (artificial selection) and selection that happened naturally (natural selection). In fact, one of the key pieces of evidence Darwin used to support his theory came from artificial selection. Darwin showed how selective breeding of crops and animals led to highly specialized varieties with unique traits. Breeders practised artificial selection when they chose only certain individuals with the most desirable characteristics to breed. This resulted in cows that give more milk, sheep that produce more wool, and faster racehorses. Darwin argued that since artificial selection could produce big changes over relatively short periods of time, natural selection could produce even bigger changes if given thousands or millions of years.

The deliberate creation of new livestock breeds or crops is one way that humans are directly affecting the evolution of species. Humans are also indirectly affecting evolution by changing the environment around the world. Pollution, climate change and habitat destruction are all changing the selection pressures on species. The changes caused by humans are occurring faster than most species can adapt. This means many species are becoming extinct, although a few—such as the Norway rat, pigeon, house mouse and lawn weeds—are actually doing better in human-dominated landscapes.

One dramatic new form of artificial selection comes from our ability to genetically modify organisms. Using biotechnology, we can now insert genes into organisms that would never occur there naturally.

Genetically Modified Foods: Helpful or Harmful Artificial Selection?

Perhaps the most controversial application of artificial selection is in genetically modified foods (GMF)—crop plants created for human or animal consumption using the latest molecular biology techniques. These plants have been modified in the laboratory by inserting genes from other species to add desired traits such as increased resistance to herbicides or improved nutritional content. Once the genes are inserted, they become part of the plant's genome and are passed down through reproduction just like all the other genes.

Most major crop plants, including corn, rice, wheat and barley, have been genetically modified. This practice has generated much controversy. Many people worry about potential environmental damage or dangers to human health. Others argue that the benefits outweigh any potential risks.

Advantages of GMFs

1. Pest Resistance

Crop destruction by insects can be devastating, resulting in huge financial losses for farmers and starvation in developing countries. Farmers typically use many tons of chemical pesticides annually. Growing GMFs can help eliminate the application of pesticides and reduce the cost of bringing a crop to market.

2. Herbicide Tolerance

Crop plants genetically engineered to be resistant to herbicides could help prevent environmental damage by reducing the amount of herbicide needed. Typically, the herbicide would need to be sprayed only once to kill off weeds, without killing the modified crop plants.

3. Disease Resistance

There are many viruses, fungi and bacteria that cause plant diseases, and GMFs can be modified to resist these diseases.

4. Cold Tolerance

Cold spells can wipe out entire crops of food, devastating farmers and resulting in food shortages. Scientists have introduced a gene from cold-water fish into plants such as tobacco and potatoes, which helps prevent freezing and makes them resistant to cold spells.

5. Drought Tolerance/Salinity Tolerance

Genetically modifying plants so that they can withstand long periods of drought or high salt content in soil and groundwater will help make it possible to grow crops in places they couldn't grow before.

6. Nutrition

Malnutrition is common in developing countries where people rely on a single crop, such as rice, as the staple of their diet. However, rice does not contain adequate amounts of all the nutrients needed to prevent malnutrition. If rice could be genetically engineered to contain additional vitamins and minerals, nutrient deficiencies could be reduced.

7. Pharmaceuticals

Medicines and vaccines are often expensive to produce and sometimes require special storage conditions. Scientists are working to develop edible vaccines in plants. If successful, people could get vaccinated by eating a tomato, for example.

8. Phytoremediation

Not all genetically modified plants are grown for food. Soil and groundwater pollution continues to be a problem in all parts of the world. Plants such as poplar trees have been genetically engineered to clean up heavy metal pollution from contaminated soil. When plants are modified to help fix an environmental problem, this process is called phytoremediation..

Disadvantages of GMFs

1. Accidental Harm to Other Organisms

Recent research has demonstrated that pollen from genetically modified corn caused high death rates in monarch butterfly caterpillars. Monarch caterpillars feed on milkweed plants, not corn, but the fear is that if pollen from GM corn is blown by the wind onto milkweed plants in neighbouring fields, the caterpillars could eat the pollen and perish.

2. Reduced Effectiveness of Pesticides

Some scientists are concerned that insects will become resistant to crops that have been genetically modified to produce their own pesticides.

3. Gene Transfer to Non-target Species

Another concern is that herbicide-tolerant GMFs will accidentally interbreed with wild weeds and hence transfer the herbicide tolerance genes from the crops into the weeds. These "superweeds" would then be herbicide-tolerant as well, and might grow out of control.

4. Allergenicity

There is speculation that inserting a gene into a plant may create a new allergen or cause an allergic reaction in susceptible individuals. For example, cold-water fish genes have been inserted into tomatoes to give them tolerance to freezing. But some people are dangerously allergic to fish, and they were surprised to find they were suddenly dangerously allergic to tomatoes.

5. Unknown Effects on Human Health

There is a growing concern that introducing foreign genes into food plants may have an unexpected and negative impact on human health. Some scientists feel that more research is required before GMFs are allowed to become more widespread.

6. Economic Concerns

Bringing a GMF to consumers is a costly process, and can be very profitable for the biotech companies that invest in their creation. With an increase in patents, consumer advocates are worried these new plant varieties will raise the price of seeds so high that small farmers in developing countries will not be able to afford seeds for GMF crops.

Support Questions

11. Explain the difference between artificial and natural selection. Provide an example of each. Suggested answer

12. How is artificial selection dependent on variation in nature? Suggested answer

13. Imagine you are an environmentalist (you work to save the environment) researching the impact of GMFs. State one advantage and one disadvantage of GMFs that would be relevant to your work. Suggested answer

Key Questions

Now work on your Key Questions in the online submission tool. You may continue to work at this task over several sessions, but be sure to save your work each time. When you have answered all the unit's Key Questions, submit your work to the ILC.

(18 marks)

4. What role does natural variation play in the process of natural selection and, ultimately, evolution? **(3 marks)**

5. Give three lines of evidence that Darwin used to support his theory of evolution by natural selection, and briefly explain how each one provided support. **(6 marks: 2 marks for each)**

6. Imagine you are a farmer researching the impact of GMFs. What is one advantage and one disadvantage that would be relevant to your work? Explain each. **(4 marks)**

7. Explain how natural selection could have produced the modern long-necked giraffe from short-necked ancestors. **(5 marks)**

Now go on to Lesson 3. Send your answers to the Key Questions to the ILC when you have completed Unit 1 (Lessons 1 to 4).