Biology 3211 Unit 3A: Evolutionary change

What is **evolution?**

The relative change in the characteristics of a population over successive generations. It is important to note that individuals do not evolve, populations evolve.

The gradual change in allele frequencies in a population is called **microevolution**. An example of microevolution is the development of DDT-resistance in *Anopheles* mosquito populations.

Large-scale evolutionary changes, including the formation of new species or other taxa, is called **macroevolution**. The evolutionary changes that produced the first animals with arthropod features, as well as the changes that resulted in the first insect-like arthropods and the first dragonfly-like insects, were major steps in evolution. Modern classification schemes of biodiversity are built on our understanding of macroevolution and evolutionary relationships.

Organisms constantly face environmental challenges that limit populations. Organisms that survive long enough to reproduce have the opportunity to pass along to their offspring the genetic information that helped them survive.

How does this help to explain changes in populations from one generation to another? The answer lies in **Adaptations** and **Variations.**

Adaptation: a structure, behaviour, or physiological process that helps an organism survive and reproduce in a particular environment.
Example:

- Camouflage
- changing physiology of a harbour seal, whose heart rate slows, conserving oxygen when it dives.

Adaptations are the result of a **gradual change** in the genetic traits of members of a population **over time.**

How do adaptations develop?

Variations: refers to the visible or invisible differences among some members of a population.

Not all variations become adaptations. A variation in an individual can be an **advantage** or **disadvantage** or have **no effect** on the individuals as they live and interact in their environment.

Example: A small variation in the way a birds beak forms may make it easier or harder to get food or have no affect at all.

How much variation exist within a population? Within this classroom?

Investigation 16A: Variations Great and Small, page 638.

But How do these variations arise?

1. Through sexual reproduction and crossing over! Offspring have a combination of genetic material from both parents. The number of possible combinations of genes that offspring can inherit from their parents results in great genetic variation among individuals within a population.

2. Mutations! Mutations are a source of variation in populations. Mutations happen continuously in the DNA of any living organism. Some mutations are *neutral,* and so will not appear to have any effect on a cell. Whatever the result, a *somatic cell mutation* disappears when the organism dies. A *germ line mutation*, however, occurs in a sperm or egg cell, and so the mutation may be passed down to succeeding generations. Thus, mutations are a significant source of genetic variation in populations.

Selective Advantage

In some instances, a mutation enables an organism to survive in its environment better, which, in turn, means that the organism is more likely to survive and reproduce. This situation is more common when an organism's environment is changing. Mutations that once were no advantage, or perhaps were even a disadvantage, may become favourable in a new environment. In this situation, the mutation provides a **selective advantage** in the new environment. While a mutation can be a disadvantage in one environment, it can provide a selective advantage in another.

Recall: Sickle cell anemia and malaria!

Artificial selection.

For centuries people have used ***artificial selection*** to produce particular plant and animal varieties that consistently express desirable traits. For example, Breeding dogs, breeding horses to produce the fastest possible horse etc. However, this may select for unhealthy traits as well as desirable ones.
Ex: Pekinese and British Bulldogs are bred for flat faces, but this causes respiratory problems.

Natural Selection

Natural selection is a process that results when the characteristics of a *population* of organisms change because *individuals* with certain inherited traits survive specific local environmental conditions and, through reproduction, pass down their traits to their offspring.

The **environmental conditions** determine which individuals in a population are most fit to survive. Genes from the surviving individuals are passed on to the offspring.

An abiotic environmental condition can be said to select *for* certain characteristics in some individuals and select *against* different characteristics in other individuals. In this way, the environment exerts **selective pressure** on a population.

If the selective pressure becomes too great, a species may no longer be able to survive and reproduce. In some cases, this may lead to **extirpation** or **extinction.**

A once neutral or even negative mutation can, in some cases, mean the survival of a population. Natural selection does not anticipate change in the environment. Instead, natural selection is situational. A trait that at one time seems to have no particular relevance to survival becomes the trait that later helps individuals in a population survive and reproduce in a changed environment.

Examples of natural selection.

- *The peppered moth occurs in one of two variations.*
  - *Flecked (White wings with flecks of black)*
  - *Black (Wing colour is black)*

  Until the mid 1900's, the flecked moths lived and fed upon lichens on trees in England. The flecked moths were camouflaged against the white background of lichens. The black moths were easily seen and preyed upon. The flecked moths were able to survive and pass on their genes to their offspring. During the Industrial Revolution in England, black moths were able to gain an advantage over the flecked moths. Black soot from factories killed the lichens and covered trees providing an excellent source of camouflage for black moths. Now, the flecked moths were easily seen and eaten. The black moths survived and passed their genes onto their offspring.
  In the 1950's, England introduced "Clean Air Policy". This allowed lichens to grow on trees again. As a result, the flecked moths were well camouflaged, and the black moths were easily seen and eaten. The ratio of black to flecked moths was changing again.

- Antibiotic Resistance in Staphylococcus aureus bacteria

  Activity 16.1, Evolving superbugs Page 640.

For discussion:
How might the introduction of a fishing net mesh size (10cm^2) for catching cod change the population over time?
How might global warming and the movement of polar bears south impact that population?

Developing a Theory to Explain Change

Scientific knowledge develops as people observe the world around them, ask questions about their observations, and seek answers to their questions.
A ***scientific hypothesis*** is a statement that provides one possible answer to a question, or one possible explanation for an observation Hypotheses that consistently lead to successful predictions and explanations are sometimes synthesized into a general statement that explains and makes successful predictions about a broad range of observations. Such a statement is called a ***scientific theory*.**

Early Philosophies
Plato and Aristotle believed that all life existed in a perfected and unchanging form. This view of life prevailed in Western culture for over 2000 years. By the sixteenth century, the predominant philosophy in Western culture was that all species of organisms had been created independently of one another and had remained unchanged ever since.

Georges-Louis Leclerc, Comte de Buffon (1707–1788).

One of the first people to challenge this position publicly was French naturalist Georges-Louis Leclerc. In 1749, he published the 44-volume *Histoire Naturelle*. Buffon noted the similarities between humans and apes and speculated that they might have a common ancestor. In other writings, Buffon suggested that Earth was much older than 6000 years, as was commonly believed.

Mary Anning

In 1811, a preteen named Mary Anning unearthed the ancient remains of a bizarre-looking sea creature. Later identified as a prehistoric fish called *Ichthyosaurus*, the specimen looked unlike any animal known to be living during Anning's time. Also strange were the fossilized skeletons of a marine reptile known as a plesiosaur and a flying reptile called a pterosaur, which Anning discovered and excavated when she was a young woman. Her discoveries made people question if all forms of life came into existence at the same time. These fossils provided good evidence that many life forms of the past no longer existed.

Georges Cuvier (1769–1832)-Fossil Evidence

This French naturalist is largely credited with developing the science of **paleontology**.
Cuvier found that each layer of rock is characterized by a unique group of fossil species. He also found that the deeper (older) the layer, the more dissimilar the species are from modern life. He also found evidence that new species appeared, and others disappeared over the passage of time. This evidence showed that species could become extinct. Although Cuvier recognized that some species had gone extinct, he did not believe that species evolved. He believed in **catastrophism,** the idea that catastrophic events, such as floods, earthquakes etc were violent enough to have killed numerous species each time they occurred.

Charles Lyell (1797–1875)- Lyell's *Principles of Geology*

Scottish geologist Charles Lyell rejected the idea of catastrophism. Lyell developed the theory of **Uniformitarianism.** It stated that geological processes operate at the same rate today as they always did. Lyell said the earth was millions of years old instead of 6000 yrs old. As well, Lyell theorized that slow, subtle processes could happen over a long period of time and could result in substantial changes. If Earth is slowly changing, other scientist wondered, could slow, subtle changes also occur in populations?

Jean-Baptiste Lamarck (1744–1829) -The Inheritance of Acquired Characteristics

He outlined his ideas about changes in species over time. By comparing current species of animals with fossil forms, Lamarck observed what he interpreted as a "line of descent," or progression, in which a series of fossils (from older to more recent) led to a modern species. He thought that species increased in complexity over time, until they achieved a level of perfection.

Lamarck also thought that characteristics, such as large muscles, that were acquired during an organism's lifetime could be passed on to its offspring. Lamarck called this concept the **inheritance of acquired characteristics.** Lamarck's ideas were controversial to many people, though, simply because they firmly believed that species never changed. By the 1900s, as biologists learned about cells, genes, and heredity, Lamarck's mechanism for inheritance was rejected.

Charles Darwin (1809–1882)

Naturalist Charles Darwin published the first detailed explanation of natural selection in 1859.

In 1831, 22-year-old Charles Darwin left England on the HMS *Beagle*, a British survey ship. Many of Darwin's observations surprised him. For example, he observed finch species on the Galápagos Islands that looked similar and yet distinct from one another and from any finch species on continental South America. He encountered marine iguanas and giant tortoises. At first, Darwin did not always understand the significance of many of his observations. Years later, however, many of these observations became important to his **theory of evolution by natural selection.**

See Table 16.1. for a full summary of his observations and findings

Alfred Russel Wallace (1823–1913)

Another British naturalist, independently reached conclusions that were similar to Darwin's. The findings of both scientists were made public in a presentation by Charles Lyell in 1858. Darwin and Wallace accepted that populations changed as time passed, but they were unclear *how* populations changed.

Thomas Malthus (1766–1834)

An essay by economist Thomas Malthus called *An Essay on the Principles of Population*, provided Darwin and Wallace with a key idea. Malthus had proposed that populations produced far more offspring than their environments (for example, their food supply) could support and were eventually reduced by starvation or disease. Crowding and struggle for survival (competition for resources) is what keeps populations from exploding.

Darwin and Wallace- putting it all together.

Darwin was also aware that people could select organisms with certain traits in order to breed specific varieties of plants or domestic animals. He called this process of selective breeding **artificial selection**. The traits of the selectively bred parents were inherited by the offspring. Darwin thought that a similar process of inheritance could occur in nature.

According to Darwin and Wallace, individuals with physical, behavioural, or other traits that helped them survive in their local environments were more likely to survive to pass down these traits to offspring. Darwin and Wallace reasoned that competition for limited resources among individuals of the same species would ***select for*** individuals with favourable traits—traits that increased their chances of surviving to reproduce. Darwin called this process **natural selection.**

He published his ideas in 1859 in ***On the Origin of Species by Means of Natural Selection***. Darwin proposed two main ideas in *On the Origin of Species*:

1. Present forms of life have arisen by descent and modification from an ancestral species.
2. The mechanism for modification is natural selection working for long periods of time.

Darwin proposed that all life on Earth had descended from some unknown organism. As descendants of this organism spread out over different habitats during the millennia, they developed adaptations that helped them better survive in their local environments. Darwin's theory of natural selection showed how populations of individual species became better adapted to their local environments over time.

The theory of evolution by natural selection now includes the following ideas:

1. Life forms have developed from ancestral species.
2. All living things are related to one another by varying degrees through common descent.
3. All living things on Earth have a common origin (share a common ancestor).
4. The mechanism by which one species evolves into another species involves random heritable genetic mutations. Some mutations result in a survival advantage for an individual; if so, the individual is more likely to survive and pass down this mutation to its offspring. Eventually, the successful mutation increases in the population and causes the population as a whole to start to change.

Discuss how Darwin and Lamarck had differing explanations for changes in population.

Activity 16.3, page 649.
How important was peer review in the development of these theories?

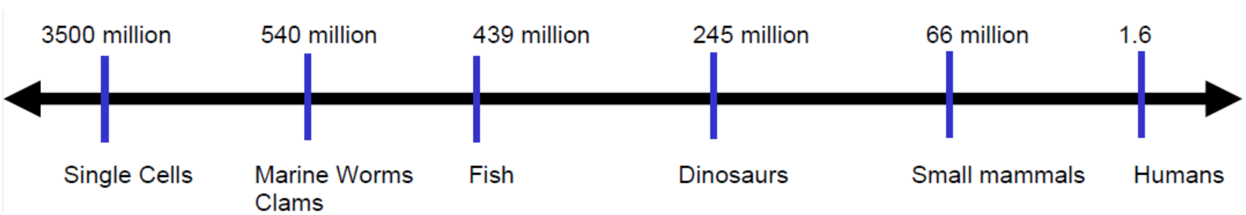
Further Evidence of evolution

1. The Fossil Record

Sedimentary rock with fossils provides a **fossil record** of the history of life by showing species that were alive in the past. The fossil record provides the following evidence:

- Fossils found in young layers of rock are much more similar to species alive today than fossils found in deeper, older layers of rock.
- Fossils appear in chronological order in the rock layers. So, probable ancestors for a species are found in older rocks, which usually lie beneath the rock in which the later species is found.
- Not all organisms appear in the fossil record at the same time.

Fossils of complex, multicellular organisms can be found in more recent rock formations. This supports the idea that has evolution has occurred, species of organisms have become more complex through time.



In order for fossils to be useful, we need to know their ages. There are a few ways to date fossils.

Index fossils.
Fossil species that are known to be common during a certain time can be used as **index fossils**. These indicate the approximate age of the rock in which they are found, as well as the age of other fossils found in the same layer.

Radiometric dating
Another way to date fossils is **radiometric dating**. This method uses measurements of certain radioactive isotopes to calculate the absolute age in years of rocks and minerals. Many radioactive isotopes decay into isotopes of other elements at known rates.

Carbon-14, for example, has a half-life of 5730 years. In other words, every 5730 years, half of the carbon-14 in a sample will decay into nitrogen-14. Scientists can compare the ratio of carbon-14 to nitrogen-14 in a fossil to determine its age.

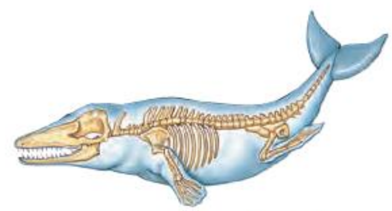
Transitional Fossils

The fossil record sometimes appeared incomplete. There were often “gaps” between fossils of ancestral species and modern ones.
Transitional fossils— fossils that show intermediary links between groups of organisms—has helped scientists better understand the process and relationships between groups of organisms. Transitional fossils link the past with the present.

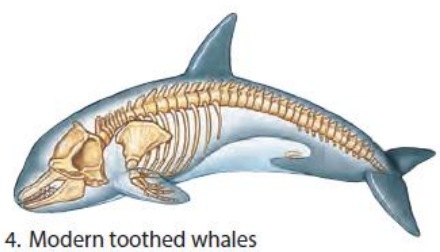
These fossils link present-day whales to terrestrial ancestors.

1. *Pakicetus attocki* lived on land, but its skull had already evolved features characteristic of whales.

2. *Ambulocetus natans* likely walked on land (as modern sea lions do) and swam by flexing its backbone and paddling with its hind limbs (as modern otters do).



3. *Rodhocetus kasranil's* small hind limbs would not have helped it swim, much less walk.



4. Modern toothed whales

Similarly, fossils of *Archaeopteryx* show a transitional stage in the fossil record because this species had characteristics of both reptiles (dinosaurs) and birds. *Archaeopteryx* had feathers, but, unlike any modern bird, it also had teeth, claws on its wings, and a bony tail.

Fossils provide the basis by which the subdivisions of the **Geologic Time-scale** are divided.

The **geological time scale** in Figure 16.11 shows when organisms first appear in the fossil record. The earliest life forms to be preserved were prokaryotic cells from about 3.2 billion years ago. Fossils of complex, multicellular organisms can be found in more recent rock formations from about 590 million years ago.

2. Biogeography

Biogeography is the study of the past and present geographical distribution of different types of organisms.
Darwin and Wallace hypothesized that species evolve in one location and then spread out to other regions.

- Geographically close environments are more likely to be populated by related species than are locations that are geographically separate but environmentally similar.
- Animals found on islands often closely resemble animals found on the closest continent. This suggests that animals on islands have evolved from mainland migrants, with populations becoming adapted over time as they adjust to the environmental conditions of their new home.
- Fossils of the same species can be found on the coastlines of neighbouring continents. For example, fossils of the reptile *Cynognathus* have been found in Africa and South America. The theory of plate tectonics explains these observations.
- Closely related species are almost never found in exactly the same location or habitat.

3. Comparative Anatomy

This is a comparison of physical structures in differing organisms that may suggest a common ancestor. Three methods are looked at:

- Homologous Structures: These are body structures in different species which have the same origin but differ in structure and function.
  Ex: Human arm, frog leg, bat wing, horse leg
  These structures all have a similar number of bones/ligaments suggesting they came from a common ancestor, but they all have a different structure and function. These structural elements are arranged to be best suited for different functions: walking, flying, or swimming.

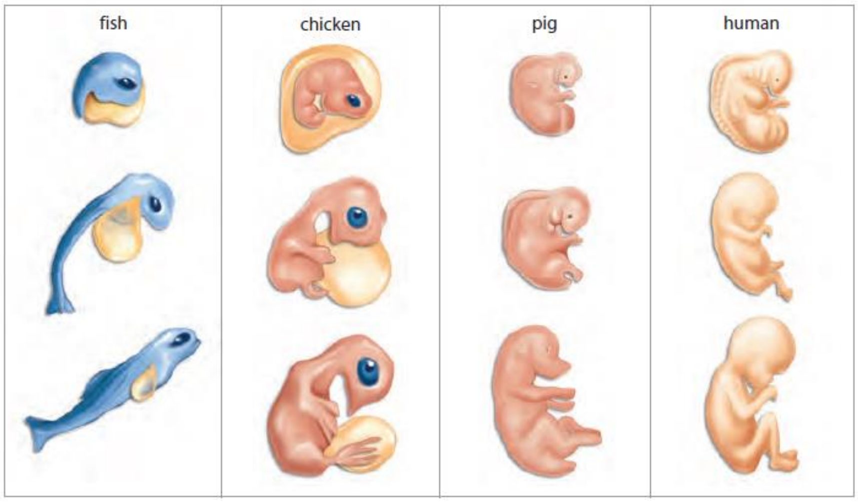
- Analogous Structures: These are structures that have different origins, but similar function.
  Ex: bird and insect wings.

There is a tendency among species living under the same conditions to develop similar body plans. If the species are not closely related, this evolutionary trend is known as **convergent evolution**.

- Vestigial Structures: These are structures that were functional in ancestors but have no current function.
  Ex: Pelvic bones in baleen whales, wings in ostriches.

4. Embryology

The embryos of different groups of organisms exhibit similar stages of embryonic development. The similarities among embryos in related groups (such as vertebrates) point to a common ancestral origin.
It follows that related species would share both adult features and embryonic features.



5. Molecular Biology and Genetics

The evolutionary relationships among species are reflected in their DNA and proteins. The field of molecular biology developed as technologies to identify molecules such as DNA and proteins developed. This field has provided evidence that helps to support the idea of common ancestry and evolution through natural selection. The fact that all organisms use DNA as their genetic material supports the idea that all life has a common ancestor. Scientists can infer how closely related two species are by comparing sequences in amino acids, RNA, and DNA, or by comparing chromosomes as a whole. Similar patterns can indicate evolutionary relationships.

Activity 16.5 page 656– How close are we?

Speciation and the pace of evolution

What Is a Species?

A biological **species** consists of populations that can interbreed and produce a group of viable offspring, which can also reproduce in nature.

Speciation: the formation of new species.

Biological species that are geographically isolated cannot interbreed. Biological species can also be described as being **reproductively isolated** from other species.

We therefore can describe species as being isolated by two means:

- Geographical barriers
- Biological barriers.

Geographical barriers, such as mountains and rivers, prevent interbreeding and result in speciation because they keep populations *physically* separated. After a long period of time, speciation will occur. The separated populations will no longer be able to mate and reproduce successfully with other members of the original population.
The geographic isolation of a population does not have to be maintained forever for speciation to occur. It must be maintained long enough, however, for the population to become reproductively incompatible with the original population.

Biological Barriers
Even if the ranges of species overlap, they may have many features that act as **biological barriers**, which keep their populations reproductively isolated. Biological barriers can be pre-zygotic or post-zygotic.

As its name suggests, **pre-zygotic reproductive isolating mechanisms** prevent organisms from different species mating or prevent successful fertilization of the eggs of one species by the sperm of the other.

In rare cases in nature, the sperm of one species successfully fertilizes an egg of another species and a zygote is produced. Three **post-zygotic isolating mechanisms** prevent these hybrid zygotes from developing into viable, fertile adults.

Pre-zygotic reproductive isolating mechanisms

There are five kinds of pre-zygotic reproductive isolating mechanisms.

1. **behavioural isolation:** biological barrier in which species-specific signals or behaviours prevent interbreeding with closely related species.

   For example: Male birds use distinct calls that are recognized by other birds of the same species

2. **habitat isolation:** biological barrier in which different species live in the same general area, but use different habitats, and so rarely encounter each other.

   For example: the blackspotted stickleback builds nests in brackish waters, where seawater and freshwater mix; the three-spined stickleback builds nests in fresh water.

3. **temporal isolation:** timing barriers that prevent species in the same habitat from interbreeding; species may mate or flower at different times of the day, in different seasons, or in different years.

   For example: the blackspotted stickleback breeds slightly later in the spring than the three-spined stickleback.

4. **mechanical isolation:** biological barrier in which closely related species have incompatible reproductive structures, and so either cannot mate, or, in the case of plants, cannot be pollinated by the same species of pollinator.

   For example: Among insects, for example, genital anatomy is so distinctive that it is often used to classify species.

5. **gametic isolation:** biological barrier, such as a chemical marker on an egg, that prevents eggs and sperm from different species fusing to form a zygote.

   For example: Many marine animals, including corals, clams, and sea cucumbers, release their gametes into open water. The sperm recognize eggs of their own species through chemical markers on the surface of the eggs. The sperm will not recognize an egg of a different species, and so will not fertilize this egg.

Post-zygotic isolating mechanisms

1. **hybrid inviability:** a genetic incompatibility of interbred species that stops development of the hybrid zygote during its development.

   For example: hybrid embryos between sheep and goats die in early development before birth.

2. **hybrid sterility:** a biological barrier that exists between two species because, although they can mate and produce hybrid offspring, the offspring are sterile.

   For example: Horse + donkey = Mule (sterile)

3. **hybrid breakdown:** a biological barrier that occurs when first generation hybrids mate with each other or with an individual from either parent species, and the offspring are either sterile or weak.

   For example: For example, different species of cotton plants can produce fertile hybrids, but the offspring of the hybrids die as seeds or early in development.

Transformation and Divergence

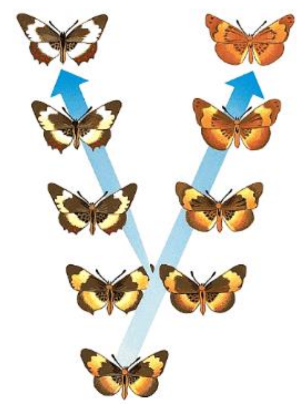
There are two general pathways that can lead to the formation of new species, or **speciation**.

A new species may result from accumulated changes in the population over a long time. A new species gradually develops as a result of mutation and adaptation to changing environmental conditions, and the old species is gradually replaced. This is known as **transformation.**

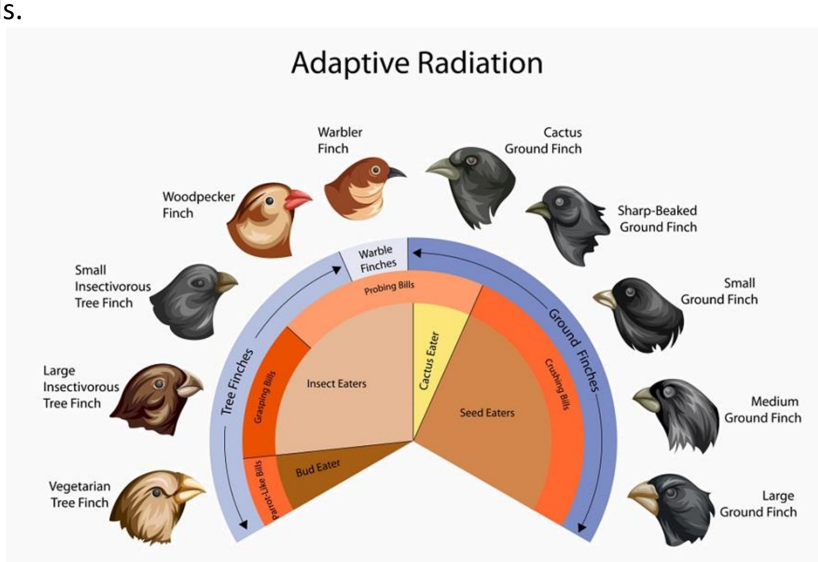
In the second pathway to speciation, one or more species arise from a parent species that continues to exist. This is known as **divergence.**

The diversification of a common ancestral species into a variety of species, all of which are differently adapted, is called **adaptive radiation**. Adaptive Radiation is an example of Divergent Evolution

Note that both pathways to speciation are the result of natural selection. The second pathway increases biological diversity because it increases the number of species.



The speciation of finches throughout the Galápagos Islands is an example of adaptive radiation. New species developed as they evolved in response to the unique environments on individual islands.



Co-evolution

Changing environments and interactions among individuals of the same, or different, populations may act as selective pressures in the process of natural selection. For example, different, closely associated species **co-evolve** when the evolution of each species depends on the evolution of the other. As a result, factors that affect one species, positively or negatively, may indirectly affect another.
The human species is one with the potential to affect all others.

The Pace of Evolution- How fast is evolutionary change?

There are two theories/models that explain how fast evolution occurs. Both examine the Fossil record.

Gradualism: a model that describes evolution as slow, steady, and linear, with the accumulation of many small changes producing large changes.
The fossil record, however, rarely reveals fossils that show this gradual transition. Instead, paleontologists most often find species that appear suddenly in the fossil record and then Disappear.

Punctuated equilibrium: a model that describes evolution as consisting of long periods of stasis, interrupted by periods of rapid change.
Evidence in the fossil record that show periods of rapid change (for example, rapid speciation after mass extinctions). It is important to note that **extinction** occurs when a species is unable to change in its environment. This may occur at a gradual rate or in mass extinction events.

It is now accepted that both models of evolutionary change are at work. Though the pace of evolution is still debated, the theory of evolution by natural selection forms the backbone of biology as a science and provides a framework to understand the world in which we live.

Population Genetics

population genetics: the study of genetic variation in populations.

gene pool: sum of all alleles for all the genes in a population. In other words, a gene pool is the sum of all the genetic variation that can be passed on to the next generation.

Recall that genes are carried on chromosomes and control the inheritance of traits
A gene can have more than one form. Each form of a gene is called an **allele** and you can have **recessive** and **dominant** forms.

The alleles that are carried by the sperm and the egg combine during fertilization to produce a **genotype**. Thus, three genotypes of any trait is possible.

For example: BB, Bb, or bb.

A **genotype frequency** is the proportion of a population with a particular **genotype.** It is usually expressed as a decimal.

Suppose, for example, that a sample of a mouse population includes 72 black mice with the genotype *BB*, 96 black mice with the genotype *Bb*, and 32 white mice with the genotype *bb*

Since there are 200 mice in the sample, and we assume that white is recessive to black, the genotype frequency of the *bb* genotype is 32/200= 0.16. This can also be expressed as 16%.

Since the numbers of mice with *BB* and *Bb* genotypes are given, the frequencies of these genotypes can also be determined.
The frequency of the *BB* genotype is72/200= 0.36 (36 percent).
The frequency of the heterozygous (*Bb*) genotype is 96/200= 0.48 (48 percent).

Notice that the sum of all three genotype frequencies is 1.00, or 100 percent.

Recall that an organism's phenotype is its visible or measurable traits.

A **phenotype frequency** is the proportion of a population with a particular **phenotype,** expressed as a decimal or percent. For the black and white mice, the phenotype frequency for white coat colour is the same as the genotype frequency for the *bb* genotype. This is because white coat colour is a recessive trait.

An **allele frequency** is the rate of occurrence of a particular allele in a population, with respect to a particular gene. An allele frequency is usually expressed as a decimal.
Since diploid organisms have two possible alleles for every gene, the total number of alleles in a population is twice the number of individuals. The sample of 200 mice, for example, has a total of 400 coat colour alleles.

The number of *B* or *b* alleles in the mouse population can be found by simply counting these alleles:

72 *BB* mice with 72 × 2 = 144 *B* alleles
and 0 × 72 = 0 *b* alleles

96 *Bb* mice with 96 × 1 = 96 *B* alleles
and 96 × 1 = 96 *b* alleles

32 *bb* mice with 32 × 0 = 0 *B* alleles
and 32 × 2 = 64 *b* alleles

Totals: 144 + 96 + 0 = 240 *B* alleles
and 0 + 96 + 64 = 160 *b* alleles

The frequency of each allele is found by dividing the incidence of the allele by the total number of alleles in the sample. Thus, the frequency of the *B* allele is 240/400 = 0.60, or 60 percent.
The frequency of the *b* allele is 160/ 400 = 0.40, or 40 percent.
Allele frequencies add up to 1.00—that is, 0.60 + 0.40 = 1.00 (100 percent).

The Hardy-Weinberg Principle

In 1908, two scientists, working independently, provided a mathematical model for studying population genetics.
Godfrey Hardy, an English mathematician, and Wilhelm Weinberg, a German physician, each showed that allele frequencies in a population will remain the same from one generation to the next, as long as five conditions are met:

1. The population is large enough that chance events will not alter allele frequencies.
2. Mates are chosen on a random basis.
3. There are no net mutations.
4. There is no migration.
5. There is no natural selection against any of the phenotypes.

The prediction based on these conditions is known as the **Hardy-Weinberg principle**.

In this case, the letter ***p*** represents the frequency of the dominant allele in the population.

The letter ***q*** represents the frequency of the recessive allele.

Since there are only two alleles, when their frequencies are added together, the sum must be 1.00, or 100 percent of the alleles.

So $p+q=1$

To determine the frequencies of different **genotypes** in a population. We can use the following equation:

$$P^2 + 2pq + q^2 = 1$$

p^2	+	$2pq$	+	q^2	=	1.00
frequency of homozygous dominant genotype		frequency of heterozygous genotype		frequency of homozygous recessive genotype		all the individuals in the population (100 percent)

This equation is known as the **Hardy-Weinberg equation**.

So, p^2=BB 2pq=Bb and q^2=bb

The Hardy-Weinberg equation can be used to calculate the proportion of a population that carries recessive alleles for genetic conditions, such as sickle cell anemia or cystic fibrosis. It can also be used to calculate the number of individuals with a specific genotype, such as the number of carriers of a genetic condition.

Sample Problem 1

Albinism in a Snake Population

In a randomly mating population of snakes, one out of 100 snakes counted is albino, a recessive trait. Determine the theoretical percentage of each of the genotypes in the population.

What Is Required?

To determine the values for p^2, $2pq$, and q^2, which represent the frequencies of the *AA*, *Aa*, and *aa* genotypes in the population

What Is Given?

The value of q^2: The proportion of snakes that are albino and thus have the *aa* genotype is $\frac{1.00}{100.00}$.

$p + q = 1.00$

Plan Your Strategy

Change the value of q^2 to a decimal.
Take the square root of the value of q^2 to find the value of q.
Subtract q from 1.00 to find the value of p.
Find the values of p^2 and $2pq$.
Express p^2 and $2pq$ as percents.

Act on Your Strategy

Step 1

$$q^2 = \frac{1.00}{100.00} = 0.0100, \text{ or } 1.00\ \%$$

Step 2

$$\sqrt{q^2} = \sqrt{0.0100}$$
$$q = 0.100$$

Step 3

$$p + q = 1.00$$
$$p = 1.00 - q = 1.00 - 0.100 = 0.900$$

Step 4

$$p^2 = (0.900)(0.900) = 0.810, \text{ or } 81.0\ \%$$
$$2pq = 2(0.900)(0.100) = 0.180, \text{ or } 18.0\ \%$$

The theoretical percentages of the genotypes are 81.0 percent *AA*, 18.0 percent *Aa*, and 1.00 percent *aa*.

Check Your Solution

$$p^2 + 2pq + q^2 = 1.00, \text{ or } 100\ \%$$
$$81.0\ \% + 18.0\ \% + 1.00\ \% = 100\ \%$$
$$100\ \% = 100\ \%$$

Sample Problem 2

Wing Length in Fruit Flies

A single pair of alleles codes for one of the genes that controls wing length in fruit flies (*Drosophila melanogaster*). The long wing allele (L) is dominant to the short wing allele (l). If 40 fruit flies out of 1000 that are counted have short wings, how many fruit flies out of 1000 would be expected to be heterozygotes?

What Is Required?

To determine the number of fruit flies that are heterozygous (Ll) for the wing length gene, given a population sample (N) of exactly 1000

What Is Given?

The proportion (q^2) of homozygous recessive (ll) fruit flies in the sample, $\frac{40}{1000}$

Plan Your Strategy

Change the frequency of q^2 to a decimal.
Take the square root of the value of q^2 to find the value of q.
Subtract q from 1.00 to find the value of p.
Find the value of $2pq$.
Multiply the population size (N) by the frequency of the heterozygous genotype ($2pq$).

Act on Your Strategy

Step 1

$$q^2 = \frac{40.0}{1000} = 0.040$$

Step 2

$$\sqrt{q^2} = \sqrt{0.0400}$$
$$q = 0.200$$

Step 3

$$p + q = 1.00$$
$$p = 1.00 - q = 1.00 - 0.200 = 0.800$$

Step 4

$$2pq = 2(0.800)(0.200) = 0.320$$

Step 5

$$\text{number of heterozygotes} = (2pq)(N) = (0.320)(1000.0) = 3.2 \times 10^2$$

The population sample would be expected to contain exactly 320 fruit flies that are heterozygous (Ll) for the wing length gene.

Check Your Solution

$$p^2 + 2pq + q^2 = 1.00$$
$$(0.800)^2 + 0.320 + 0.0400 = 1.00$$
$$0.640 + 0.320 + 0.0400 = 1.00$$
$$1.00 = 1.00$$

Why do we wish to apply the Hardy-Weinberg principle?

The Hardy-Weinberg principle not only provides a method for measuring the amount of variation within a gene pool, but also allows geneticists to compare allele frequencies in a population at different times. If there is no change in allele frequencies over time, then the population is said to be at **genetic equilibrium** (also called *Hardy-Weinberg equilibrium*). A population at genetic equilibrium is not changing or evolving. If, on the other hand, there *is* a change in allele frequencies over time, then one of the conditions of the Hardy-Weinberg principle is not being met and the population may be evolving. The gradual change in allele frequencies in a population is called **microevolution**.

Investigation 17B pages 684 & 685. Testing the Hardy-Weinberg principle.

Causes of gene pool change

Genetic diversity is the degree of genetic variation within a species of population. Changes in genetic diversity over time are evidence that the conditions of the Hardy-Weinberg principle have not held true.

There are many processes that can cause changes in gene pools. Such as:

- Genetic mutations
- gene flow
- non-random mating (sexual and artificial selection)
- genetic drift
- natural selection (*already discussed*)

Together, over a few generations, they can either *expand* or *limit* genetic variation in a population.

Mutations

An inheritable mutation has the potential to affect an entire gene pool. Inheritable mutations may diversify a gene pool. The more genetic variation there is in a population, the greater the chance that a variation will be present and provide a selective advantage in a changing environment.

Ex: California Ground squirrel having the ability to break down rattlesnake poison.

Gene Flow

Gene flow describes the net movement of alleles from one population to another due to the migration of individuals. Often, an individual from one population will mate with members of a nearby population and may bring new alleles into the gene pool of the nearby population. As a result, genetic diversity in the nearby population may increase. Having greater genetic diversity may help this population survive.
While gene flow increases genetic diversity in one population, it reduces genetic differences among populations. As a result, adjacent populations tend to share many of the same alleles. If gene flow happens enough between two neighbouring populations, they may eventually merge into one population with a common genetic structure.

Non-Random Mating

Random mating in a population means that there is no way to predict which males will mate with which females, or which females will mate with which males. The probability would depend on the allele frequencies in the population. Random mating is uncommon in natural populations however for two main reasons:

1. **Preferred phenotypes/Sexual selection**

In animal populations, individuals may choose mates based on their physical and behavioural traits. This is a form of **non-random mating** because it prevents individuals with particular phenotypes from breeding. Only the individuals that mate will contribute to the gene pool of the next generation. This **Sexual selection** is a special case of natural selection in which a particular phenotype improves an individual's chances of obtaining a mate. Sexual selection generally involves competition among males through combat or visual displays to females. The visible differences between males and females—known as **sexual dimorphism**—are obvious in many animal species. The antlers of male deer and bright coloration of some male birds are two examples. Sexual dimorphism, along with courtship displays and other mating behaviours, often play a role in sexual selection.

2. **Inbreeding** is another example of non-random mating. Inbreeding occurs when closely related individuals breed together. Since close relatives share similar genotypes, inbreeding increases the frequency of homozygous genotypes. Ex: Self pollination of flowers.

Note: As homozygous genotypes become more common, harmful recessive alleles are more likely to be expressed. Negative affects of inbreeding are sometimes seen in purebred farm animals and pets, which tend to have a higher incidence of deformities and health problems. Inbreeding can also have a positive effect on a population, however. If homozygous recessive individuals fail to breed, and there are fewer heterozygous individuals each generation, harmful recessive alleles will be eliminated from the gene pool over time. Also, in wild plant populations, self-fertilization may allow individual plants to reproduce even when they are isolated from one another or there are few pollinators in the area. In addition, people often use **artificial selection** to produce varieties of crops that consistently express desirable traits.

Genetic Drift

Genetic drift is a change in allele frequencies in a small breeding population due to chance events. Individuals within a population who do not have offspring, do not contribute genetic material to the next generation. Any unique alleles they may have will therefore be lost from the gene pool.
A small population is more likely to lose alleles from its gene pool than a large population is. In general, large populations do not experience genetic drift, because chance events are unlikely to affect overall allele frequencies. If the population size decreases relatively quickly, however, due to disease, climatic change, or extensive habitat fragmentation, genetic drift can occur.

Causes of genetic drift.

The founder effect.
The gene pool change that occurs when a few individuals start a new, isolated population is called the **founder effect**. The founder effect occurs frequently on islands such as Newfoundland.

The founders will carry some, but not all, of the alleles in the original population's gene pool. Diversity in the new gene pool will therefore be limited. Furthermore, the founders may not be
typical of the population they came from, and so previously rare alleles may increase in frequency.
The founder effect also occurs in human populations, and the lack of genetic diversity in these populations can be a medical concern. Due to the founder effect, the incidence of inherited health conditions in these populations is much higher than average.

The Bottleneck Effect
Starvation, disease, human activities, or natural disasters, such as severe weather, can quickly reduce a large population. Since the survivors have only a subset of the alleles that were present before the population declined, the gene pool will lose diversity. Gene pool change that results from a rapid decrease in population size is known as the **bottleneck effect.** This phenomenon is often seen in species driven to the edge of extinction.

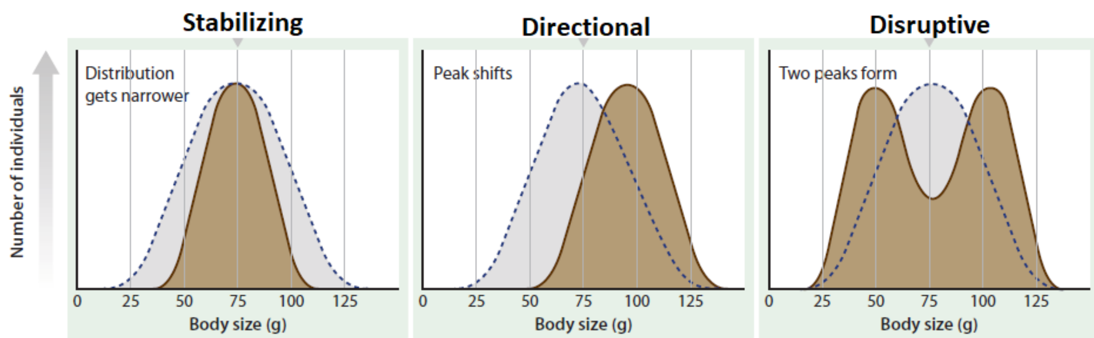
Natural Selection
Natural selection is the only process that leads directly to evolutionary adaptation. In a given environment, some individuals are better able to survive and reproduce than others are. Those individuals with greater fitness breed and pass down their favourable variations to the next generation.

Patterns of Selection
Three major types of natural selection can affect the frequency of a heritable trait in a population: stabilizing selection, directional selection, and disruptive selection.

Stabilizing selection is a form of natural selection that favours an intermediate phenotype and acts against extreme versions of the phenotype. For example, most human babies are close to 3 kg at birth. Newborns who are very small are less likely to survive than babies of intermediate size. Similarly, before successful medical interventions were common, very large newborns often experienced birth-related complications that threatened the life of both baby and mother.

Directional selection favours the phenotype at one extreme over the other. Most cases of artificial selection are directional, because they increase or decrease specific phenotypic traits. Directional selection also occurs in nature. For example, In drought years, finches with deeper beaks were more likely to survive, because they could eat the harder-to-crush large seeds as well as small seeds. In this case, natural selection favoured larger beaks over smaller or intermediate-sized beaks.

Disruptive selection favours the extremes of a range of phenotypes over intermediate phenotypes, and it may eliminate intermediate phenotypes from the population. An example is the extreme size differences in mature male coho salmon.
The smaller phenotype of a mature coho salmon averages about 500 g, while the much larger phenotype may be 4500 g or more. This size difference reflects how each phenotype gains access to females. The smaller salmon are specialized for “sneaking” opportunities to fertilize the eggs of females; the larger salmon are better adapted for fighting for access to the females’ eggs.



Human Activities and Genetic Diversity

Human activities can affect the genetic diversity of populations in various ways. Habitats may become fragmented when people convert large stretches of wilderness into croplands or when they develop wild areas, construct dams, or build roads.
These barriers may prevent gene flow between the split populations. Over time, the isolated populations may undergo adaptive radiation if their environments are very different. Due to genetic drift, however, each population will likely have little genetic diversity within it.
Unregulated hunting, habitat removal, and other human activities that cause populations to decline abruptly can cause a bottleneck effect followed by genetic drift. The sudden large-scale loss of genetic diversity results in inbreeding, which may cause fertility rates to decline.
Populations that lack genetic diversity are more susceptible to new diseases and other environmental changes, too.

Questions to consider:

Will biotechnology result in the evolution of new species?
Does biotechnology have the potential to impact wild populations?
Can biotechnology help preserve species?.

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