MUKUBA UNIVERSITY

BIO 470: TAXONOMY AND EVOLUTION MODULE 3

TAXONOMY AND EVOLUTION

BIO 470 MODULE 3

MUKUBA UNIVERSITY
DEPARTMENT OF NATURAL SCIENCES

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Acknowledgements

The MUKUBA UNIVERSITY DEPARTMENT OF NATURAL SCIENCES wishes to thank those below for their contribution to this BIO 470 MODULE 3:

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Contents

About this BIO 470: TAXONOMY AND EVOLUTION MODULE 3

/ TAXONOMY AND EVOLUTION BIO 470 MODULE 3 has been produced by MUKUBA UNIVERSITYUniversity. All modules produced by Mukuba University are structured in the same way, as outlined below.

How this BIO 470: TAXONOMY AND EVOLUTION MODULE 3 is structured

The course overview

The course overview gives you a general introduction to the course. Information contained in the course overview will help you determine:

- If the course is suitable for you.
- What you will already need to know.
- What you can expect from the course.
- How much time you will need to invest to complete the course.

The overview also provides guidance on:

- Study skills.
- Where to get help.
- Course assignments and assessments.
- Activity icons.
- Units.

We strongly recommend that you read the overview *carefully* before starting your study.

The course content

The course is broken down into units. Each unit comprises:

- An introduction to the unit content.
- Unit outcomes.
- New terminology.
- Core content of the unit with a variety of learning activities.
- A unit summary.
- Assignments and/or assessments, as applicable.

Resources

For those interested in learning more on this subject, we provide you with a list of additional resources at the end of this BIO 470: TAXONOMY AND EVOLUTION MODULE 3, these may be books, articles or web sites.

Your comments

After completing Module 3 we would appreciate it if you would take a few moments to give us your feedback on any aspect of this course. Your feedback might include comments on:

- Course content and structure.
- Course reading materials and resources.
- Course assignments.
- Course assessments.
- Course duration.
- Course support (assigned tutors, technical help, etc.)

Your constructive feedback will help us to improve and enhance this course.

Course overview

Welcome to / TAXONOMY AND EVOLUTIONBIO 470 MODULE 3

/ TAXONOMY AND EVOLUTION BIO 470 MODULE 3—is this course for you?

This course is intended for people who have studied Bio 360.

You should also have studied biology at Diploma level.

Course outcomes

Outcomes

Upon completion of BIO 470 MODULE 3 you will be able to:

- *Explain* various isolating mechanisms.
- *Discuss* importance of isolation for speciation.
- *Appreciate* role of natural selection in speciation.
- *Describe* the mechanisms of natural selection.
- *Discuss* types and causes of variation.
- *Explain* role of variation in speciation.
- *Relate* speciation, natural selection and variation.

Timeframe

How long?

This module is expected to take you a minimum of 80 hours. This time should be spent on studying the module and doing the activities.

Study skills

As an adult learner your approach to learning will be different to that from your school days: you will choose what you want to study, you will have professional and/or personal motivation for doing so and you will most likely be fitting your study activities around other professional or domestic responsibilities.

Essentially you will be taking control of your learning environment. As a consequence, you will need to consider performance issues related to time management, goal setting, stress management, etc. Perhaps you will also need to reacquaint yourself in areas such as essay planning, coping with exams and using the web as a learning resource.

Your most significant considerations will be *time* and *space* i.e. the time you dedicate to your learning and the environment in which you engage in that learning.

We recommend that you take time now—before starting your self-study—to familiarize yourself with these issues. There are a number of excellent resources on the web. A few suggested links are:

- http://www.how-to-study.com/

  The "How to study" web site is dedicated to study skills resources. You will find links to study preparation (a list of nine essentials for a good study place), taking notes, strategies for reading text books, using reference sources, test anxiety.

- http://www.ucc.vt.edu/stdysk/stdyhlp.html

  This is the web site of the Virginia Tech, Division of Student Affairs. You will find links to time scheduling (including a "where does time go?" link), a study skill checklist, basic concentration techniques, control of the study environment, note taking, how to read essays for analysis, memory skills ("remembering").

- http://www.howtostudy.org/resources.php

  Another "How to study" web site with useful links to time management, efficient reading, questioning/listening/observing skills, getting the most out of doing ("hands-on" learning), memory building, tips for staying motivated, developing a learning plan.

The above links are our suggestions to start you on your way. At the time of writing these web links were active. If you want to look for more go to www.google.com and type "self-study basics", "self-study tips", "self-study skills" or similar.

Need help?

Help

Your course lecturers are:

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emmanuelkapongolo@yaoo.com

Assignments

Assignments

You are expected to submit at least one written assignment each time you complete a module. This means that at the end of this module 3, you will write and submit one assignment.

All assignments to be sent to:

The Director

Directorate of Distance Education

Mukuba University

P. O Box 20382

KITWE.

Or E-mail: info@mukuba.edu.zm

Assessments

Assessments

At the end of each unit you will find self-marked activities. These activities are meant to help you check your understanding of the content presented in the module.

You will also write a Tutor-Marked Assessment for this module. It is important that you do all the self-marked activities and Tutor-Marked Assessments because they will help you to check your progress.

Getting around this BIO 470: TAXONOMY AND EVOLUTION MODULE 3

Margin icons

While working through this BIO 470: TAXONOMY AND EVOLUTION MODULE 3 you will notice the frequent use of margin icons. These icons serve to “signpost” a particular piece of text, a new task or change in activity; they have been included to help you to find your way around this BIO 470: TAXONOMY AND EVOLUTION MODULE 3.

A complete icon set is shown below. We suggest that you familiarize yourself with the icons and their meaning before starting your study.

Activity	Assessment	Assignment	Case study
Discussion	Group activity	Help	Note it!
Outcomes	Reading	Reflection	Study skills
Summary	Terminology	Time	Tip

Unit 1

Speciation

1.0 Introduction

There are several concepts of what constitutes a species. One of the concepts is that known as the Biological Species Concept (BSC). According to this concept, species are groups of actually or potentially interbreeding natural populations that are reproductively isolated from each other (Mayr, 1942; Dobzhansky, 1935). Formation of such species or speciation, involves the establishment of barriers which reduce gene flow between members of the same species. The key to speciation is the evolution of genetic differences between the incipient species. For a lineage to split once and for all, the two incipient species must have genetic differences that are expressed in some way which prevents mating between them, or mating is unsuccessful. These need not be huge genetic differences. But still, some difference is necessary. It could be a small change in the timing, location, or rituals of mating. This change might evolve by natural selection or genetic drift. Speciation is therefore an evolutionary process that leads to changes in the character of a species**.** Reduced gene flow plays a critical role in speciation. Modes of speciation are often classified according to how much the geographic separation of incipient species can contribute to reducing the gene flow. In this module you will learn the factors which operate in nature to cause the formation of new species, or speciation, by reducing the flow of genes between populations of the same species, and the mechanisms. You are already aware that a species is made up of populations. Each population is evolving through processes like natural selection and can sometimes over time evolve to become new species distinct from each other. Speciation being the process by which one species splits into two or more species, is at the focal point of evolutionary theory because the appearance of new species is the source of biological diversity.

Upon completion of this unit you will be able to:

Outcomes

- *Explain* isolation mechanisms.
- *Differentiate* geographical and reproductive isolation.
- *Compare* prezygotic and postzygotic mechanisms of isolation.
- *Appreciate* effect of genetic drift, adaptation and founder effect on speciation.
- *Explain* ecological isolation.
- *Explain* speciation by polyploidy.

Terminology

Patric:	Place
Allopatric:	Other place
Peripatric:	Near place
Parapatric:	Beside place
Sympatric:	Same place
Genome:	Organism's complete set of DNA including genes, containing all the biological information needed to build and maintain an organism.
Adaptation:	A variation which assists an organism or species in its survival.
Isolation:	Any means by which the many diverse species remain distinct through reduced gene flow.

1.1 Mechanisms of speciation

Speciation is a lineage-splitting event that produces two or more separate species. The illustration in **Figure 1.1** explains this. Imagine that you are looking at a tip of the tree of life or phylogenetic tree, for a species of fruit fly. Move up the phylogeny to where your fruit fly twig is connected to the rest of the tree. That branching point, and every other branching point on the tree, is likened to a speciation event. This speciation is a result of genetic changes and results in two separate fruit fly lineages, where previously there had just been one lineage.

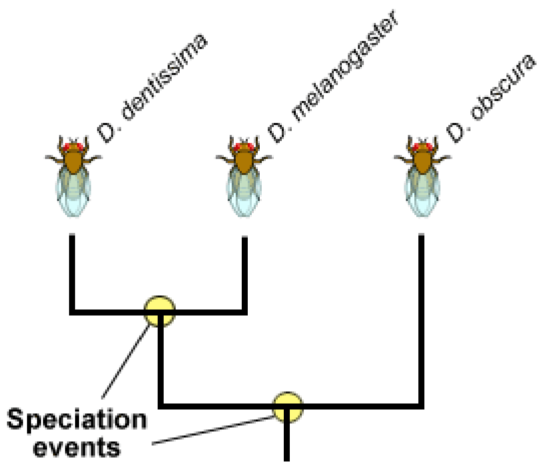


Figure 1.1: lineage splitting causing speciation.

The branching points shown on *Drosophila* phylogeny represent speciation events that took place in the past, a long time ago. There are different patterns of speciation.

But why and how does speciation happen? Let us now examine the events that lead to speciation.

1.1.1 Stages of speciation

There are 3 main stages of the speciation process.

1. Isolation-This reduces gene flow between populations of the same species.
2. Divergence-Through mutations, genetic drift, and natural selection.
3. Reinforcement- of reproductive isolation whereby hybrids are selected against.

There are different mechanisms through which speciation can take place**.**

1.1.2 Isolation as a means to achieve speciation

i. Allopatric Speciation

New species are formed in isolated geographic areas. Populations of the same species become geographically isolated when a barrier forms, separating 2 or more groups. Geographic isolation is thought to be a common way for the process of speciation to begin. This was proved by Ernst Mayr using data he collected from a wide variety of organisms in different geographical locations (Raven *et al*, 2014). Speciation starts because populations are prevented from interbreeding. Geographic isolation could be caused by rivers changing course, mountains rising, continental drift, organisms migrating, dispersal, and colonising new lands or it might just be an unfavourable habitat between the two populations that keeps them from mating with one another. Result is what was once a continuous population is divided into two or more smaller populations. Individuals from a single (ancestral species) may disperse, migrating to a new habitat. Then the geographic barrier stops gene flow. The species formed are termed **vicariant** species. Reproductive isolating mechanisms-RIMs arise over time. However if barrier is removed before reproductive barriers are effective, gene flow may be reestablished. The finches of the Galapagos Islands are a good example of the importance of geographic isolation for speciation.

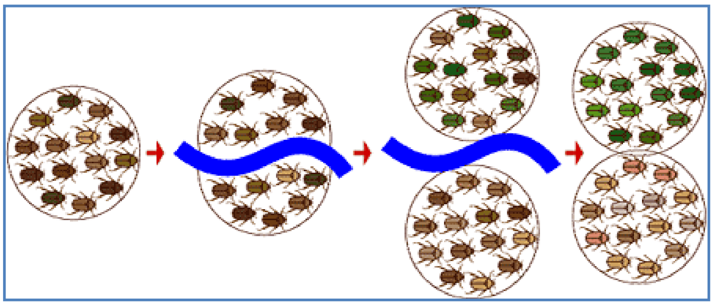


Figure 1.2: Geographic isolation

ii. Parapatric speciation

Occurs where there is no specific extrinsic (geographic) barrier. The population is continuous and extends over a broad geographic range. Individuals on one end have no chance of mating with individuals on the other end of the range. The population does not mate randomly. Individuals are more likely to mate with their geographic neighbors than with individuals in a different part of the population's range. There is reduced gene flow, but not total isolation. This may or may not be sufficient to cause speciation. In this method, divergence may happen because of reduced gene flow within the population as well as the varying selection pressures across the population's range. Speciation also requires different selective pressures at opposite ends of the range, which alters gene frequencies in groups at different ends of the range so much that, they are not be able to mate if reunited. A good example is that of the Black Lechwe in the Bangweulu Swamps and the Red Lechwe in the Kafue Flood Plains Swamps, which both constitute two different species of lechwe. An illustration of parapatric speciation is given below.

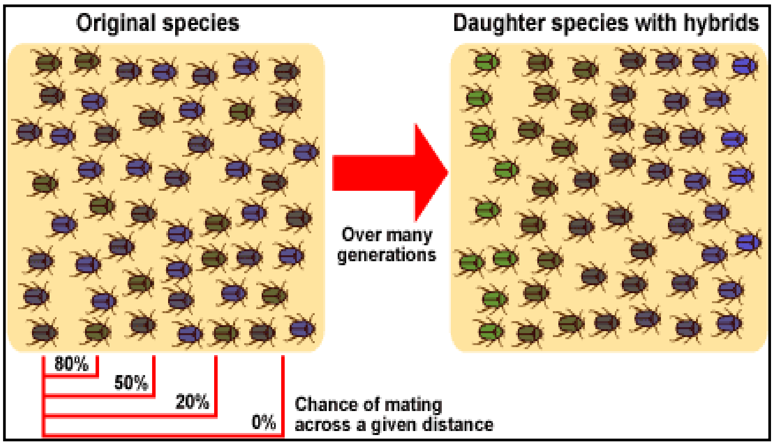


Figure1.3: Reduced gene flow across the range.

Here is another illustration with an example on plants from our local scenario:

You will have noticed that some plants live near mines where the soil has become contaminated with heavy metals. Assume that the plants around the mines have experienced natural selection for genotypes that are tolerant of heavy metals. Meanwhile, neighbouring plants that don't live in polluted soil have not undergone selection for this trait. The two types of plants are close enough that tolerant and non-tolerant individuals could potentially fertilize each other, so they seem to meet the first requirement of parapatric speciation, that of a continuous population. However, the two types of plants could have evolved different flowering times. This change could be the first step in cutting off gene flow entirely between the two groups of plants.

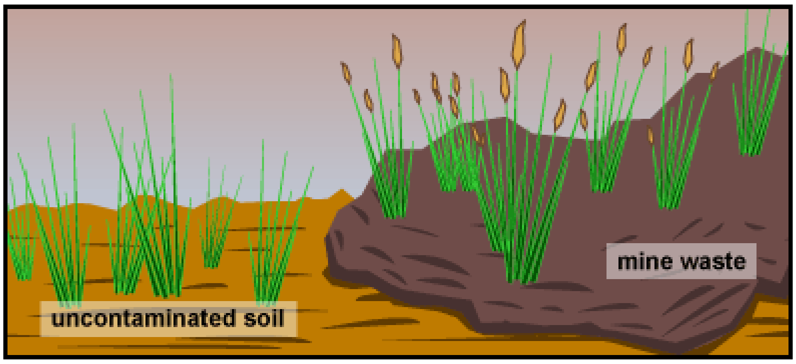


Figure 1.4: Reduced gene flow between plants

Although continuously distributed, different flowering times will begin to reduce gene flow between metal-tolerant plants and metal-intolerant plants.

iii. Peripatric speciation

This is a special version of the allopatric speciation. Peripatric speciation was originally proposed by Ernst Mayr, in the 1920's. It happens when one of the isolated populations has very few individuals. These individuals cause a *founder effect*. **Peripatric** and **peripatry** are terms from biogeography, referring to organisms whose ranges are closely adjacent but do not overlap, being separated where these organisms do not occur – for example on an oceanic island compared to the mainland. Such organisms are usually closely related species called sister species. Their distribution being the result of peripatric speciation. New species are formed in isolated peripheral populations; Populations are isolated and prevented from exchanging genes. One of the populations in peripatry is much smaller than the other. One possible consequence of peripatric speciation is that a geographically widespread ancestral species becomes paraphyletic, thereby becoming a paraspecies. Hence one species gives rise to a daughter species.

Example of paraspecies:

The evolution of the polar bear from the brown bear is a well-documented example of a living species that gave rise to another living species through the evolution of a population located at the margin of the ancestral species' range. Genetic drift is often proposed to play a significant role in peripatric speciation.

Founder effect

The founder effect is a special case of a population bottleneck. It occurs when a small group in a population splits off from the original population and forms a new one. The random sample of alleles in the just formed new colony is expected to be much smaller than the original population thus does not completely represent the correct genome of the original or parent population. The number of alleles for some genes in the original population is larger than the number of gene copies in the founders. When a newly formed colony is small, its founders can strongly affect the population's genetic make-up far into the future.

Example:

A documented example is found in the Amish migration to Pennsylvania in 1744. Two members of the new colony shared the recessive allele for *Ellis–van Creveld syndrome*. For religious reasons members of the colony and their descendants only marry among themselves. As a result of many generations of inbreeding, *Ellis-van Creveld syndrome* is now much more prevalent among the Amish than in the general population.

i. Sympatric speciation

Speciation from this mode begins with an intrinsic barrier. There is no geographic isolation. Instead there is niche differentiation where the population exists in diverse collection of microhabitats within the same geographic location. In this situation some organisms prefer to occupy one particular type of 'microhabitat' most of the time and rarely come in contact with fellow organisms, which too prefer other microhabitats. They may become so dependent on the resources in their particular microhabitats that they never even meet with others. This leads to reproductive isolation and therefore, genetic isolation. Gene flow through sexual reproduction between the organisms is limited, eventually cannot even take place. So they are now different species.

So sympatric speciation is the process through which new species evolve from a single ancestral species while inhabiting the same geographic region. It begins with a partition of the gene pool of the ancestral population. In evolutionary biology and biogeography, sympatric and sympatry are terms referring to organisms whose ranges overlap or are even identical, so that they occur together at least in some places. If these organisms are closely related (e.g. sister species), such a distribution may be the result of sympatric speciation. Ernst Mayr argued that speciation cannot occur without geographic and thereafter reproductive, isolation. He stated that gene flow is the inevitable result of sympatry. Thus, a physical barrier must be present, he believed, at least temporarily, in order for a new biological species to arise.

Sympatric speciation happens when members of a population develop some genetic difference that prevents them from reproducing with the parent type. This mechanism has occurred several times in plants, where failure to reduce chromosome number results in polyploid plants that reproduce successfully only with other polyploidy. This causes instant speciation due to non-disjunction. You will learn more of this later

An example of sympatric speciation observed in Africa is that which has occurred to Cichlid fish in Lake Victoria, East Africa.

Find out how much you have learnt.

Activity 1.1

1. Explain the following terms
   i. Speciation...
   ....
   ii. Parapatric speciation
   ....
   ....
   iii. Sympatric speciation
   ....
   ....
   iv. Peripatric speciation.
   ....
   ....
   v. Founder effect.
   ....
   ....

1.1.3 Genetic drift and adaptation

The concept of genetic drift was first introduced by Sewall Wright one of the first proponents in the field of population genetics He first used the term "drift" in 1929.Genetic drift or allelic drift is the change in the frequency of a gene variant (allele) in a population due to random sampling. Genetic drift is the gradual change in the genome of populations over time, even in the absence of natural selection. The alleles in the offspring are a sample of those in the parents, and chance has a role in determining whether a given individual survives and reproduces. Genetic drift may cause gene variants to disappear completely and thereby reduce genetic variation. Purely chance events determine which alleles (variants of a gene) within a reproductive population will be carried forward while others disappear. Therefore when there are few copies of an allele, the effect of genetic drift is larger, and when there are many copies the effect is smaller. Genetic drift is operates on random chance, and is affected by factors such as breeding population size, the geographical spread and consequent isolation of breeding groups, ecological disasters such as famine, epidemics, volcanoes and earthquakes.

The significant reduction in the size of a breeding population is called a Bottleneck effect. It produces a sudden reduction in genetic variability, and greatly increases genetic drift as the population recovers.

Documented examples

i. The founder effect is that of new populations of fruit flies founded by individuals dispersing among the Hawaiian Islands.
ii. Bottleneck effect. It is believed that humans may have had a population bottleneck about 70,000 years ago, when the breeding population decreased to as few as 15,000 individuals. This may have been caused by the eruption of Mount Toba in Indonesia, leading to global cooling; hence reduction in the population before adaptation took place.

Adaptation

An adaptation is a feature that is common in a population because it provides some improved function. Adaptations are well fitted to their function and are produced by natural selection. Adaptations can take many forms e.g. behaviour that allows better evasion of predators, a protein that functions better at body temperature, or an anatomical feature that allows the organism to access a valuable new resource. The many species of the Galapagos finches have adapted beaks specialised to feed on different foods, exemplifying what is known as adaptive radiation.

Genetic drift, works on all mutations, including those which offer no survival advantage or are neutral. Over time, it can produce changes in the genome which can lead to speciation even without environmental pressure. It can even resist and counter the effects of adaptation to weaker natural selection forces. This resistance is the reason why many harmful mutations continue to exist. But natural selection works on mutations which impact survival, favouring those which enhance the chances of survival. It is therefore the mechanism behind, the process of the gradual “fitting” of an organism to a particular niche in a given environment. You will learn more on natural selection in unit two.

Small reproductively isolated populations undergo changes due to chance factors. The smaller the population, the more susceptible it is to the random changes. The alleles in the offspring are a sample of those in the parents, and chance has a role in determining whether a given individual survives and reproduces. A population's allele frequency is the fraction of the copies of one gene that share a particular form. The smaller the allele frequency the higher the chance of being removed from the population by chance occurrences’, as the population is small. Genetic drift may cause gene variants to disappear completely and thereby reduce genetic variation.

Examples:

i. Mimicry of leaves by insects. Some insects look like small dry sticks or twigs, which is an adaptation to evade predators.

ii. Echolocation in bats is an adaptation for catching insects.

iii. Some desert-dwelling plants like the creosote bush produce toxins that prevent other plants from growing nearby, thus reducing competition for nutrients and water.

Figure 1.5: mimicry by insect

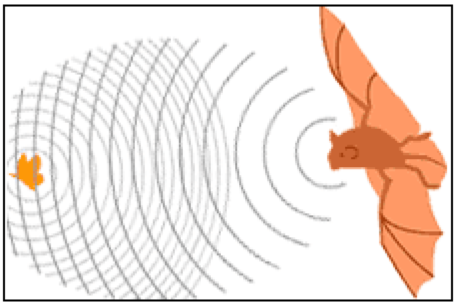


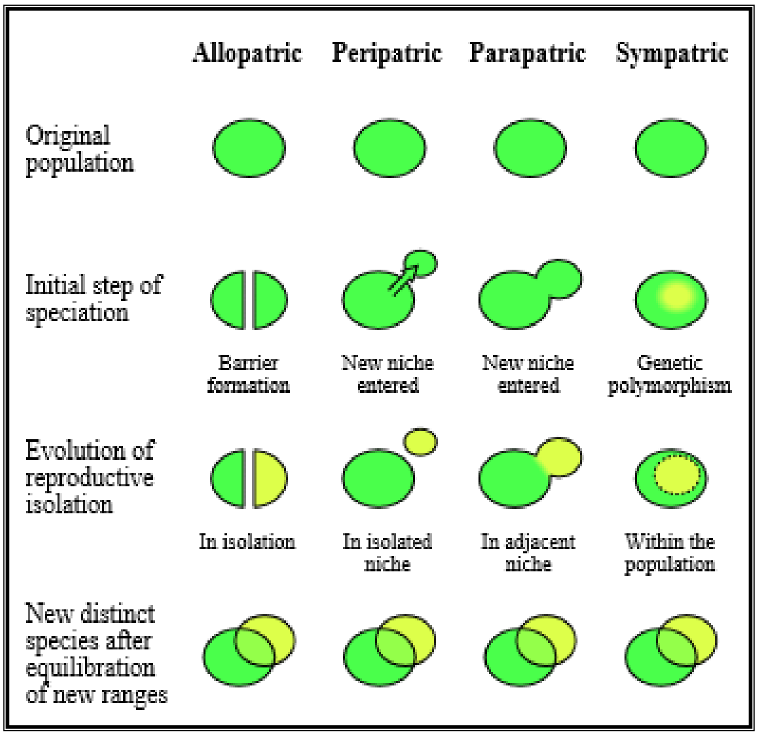
Figure 1.6: Echolocation by bats.

Geographic isolation leads to reproductive isolation. Once two populations are reproductively isolated, they are free to follow different evolutionary paths. They differentiate because:

i. Different geographic regions are likely to have different selective pressures. Temperature, rainfall, predators and competitors are likely to differ between two areas which are 100's or 1,000's of kilometres apart. Thus, over time, the two species will differentiate.

ii. Where the environments are not different, the populations may differentiate because different mutations and genetic combinations occur by chance in each. Therefore, selection will have different raw material to act upon in each population.

Table 1.2 below is a summary of the mechanisms by which speciation can take place.



Now do the following activity to find out how much you have learnt.

Activity 1.2

1. Explain

a) Geographic isolation.

....

....

b) Gene flow

....

....

2. What is

i. Genetic drift

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....

ii. Adaptation

....

....

iii. Bottleneck effect.

....

....

3. State the stages involved in isolation.

....

....

Well done. Now you can go on to learn more about reproductive isolation, in the next section.

1. 2 Reproductive isolation

The biological species concept helps us ask how species are formed, because we ask the question about how reproductive isolation comes about. Let us first examine types of reproductive isolation. The following reproductive mechanisms we shall discuss have also been dealt with in Bio 360 Module 3 Unit 1. It will be a good idea for you to refresh your memory as you extend your knowledge in this section.

1.2.1Types of Reproductive Isolation

There are many barriers to reproduction. Each species may have its own courtship displays, or breeding season, so that members of the two species do not have the opportunity to interbreed. Or, the two species may be unable to interbreed successfully because of failure of the egg to become fertilized or to develop. All are collectively known as reproductive isolating mechanisms. You therefore have isolating mechanisms before and after fertilization or union of the male and female gametes. These are commonly called pre-mating or pre-zygotic reproductive isolating mechanisms, and post-mating or post-zygotic isolating mechanisms. You already know that a zygote is the basis of a developing individual.

1.2.2 Prezygotic isolating mechanisms.

The prezygotic isolating mechanisms prevent the formation of hybrid zygotes.

i. **Ecological isolation**:

Species occupy different habitats. The lion and tiger overlapped in India until 150 years ago, but the lion lived in open grassland and the tiger in forest. Consequently, the two species did not hybridize in nature (although they sometimes do in zoos). There are differences in each species' food resources, habitat use, activity, period, or geographical range. Closely related species can be separated by their use of different habitat types, whereby they are living in different parts of the same habitat. This ecological, or habitat isolation means that the two species that could interbreed do not because the species live in different areas. For example, in India both the lion and tiger exist and are capable of interbreeding;

however, the lion lives in the grasslands and the tiger lives in the forest. By living in different habitats, the two species will not encounter one another: each is isolated from the other species. In this case it operates as a prezygotic isolation method. Where the species habitat ranges overlap and mating is possible, the hybrids produced have reduced hybrid fitness. There is an ecological mismatch between the hybrids and their environment. The hybrids are unable to survive in the environment where their parental species live.

ii. **Temporal isolation**:

Temporal isolation happens when species that could interbreed do not because the different species breed at different times. This temporal difference could occur at difference times of day, different times of the year, or anything in between. For example, the field crickets *Gryllus pennsylvanicus* and *G. veleti* become sexually mature at different seasons, one in the spring and the other in the autumn.

Some species breed at different times. In North America, five frog species of the genus *Rana* differ in the time of their peak breeding activity.

iii. Behavioural isolation: Occurs when individuals of a species reject or fail to recognise individuals of other species as mating partners because of distinct courtship and mating rituals.

Example:
Laupala palanga and *Laupala kahalensis* are two closely related species of crickets from Hawaii which exhibit behavioural isolation through males producing genetically determined songs that differ in the number

of pulses per second, such that the females are much more attracted to the song of their own male species.

iv. Mechanical isolation: refers to the differences in size and shape of the reproductive organs in different species, preventing the union of gametes. Interbreeding is prevented by structural or molecular blockage of the formation of the zygote.

v. Gametic isolation is the separation of species because of the inability of sperm to bind to the egg of a different species in animals, or the female reproductive organ of a plant preventing the wrong pollinator from landing, and genetically based differences in flower colour such that species attract their own suitable pollinators.

1.2.3 Postzygotic isolating mechanisms

Post-zygotic mechanisms are those in which hybrid zygotes fail, develop abnormally, or cannot self-reproduce and establish viable populations in nature.

i. Hybrid inviability. Development of the zygote proceeds abnormally and the hybrid is aborted. For instance, the hybrid egg formed from the mating of a sheep and a goat will die early in development.

ii. Hybrid sterility. The hybrid is healthy but sterile. The mule, the hybrid offspring of a donkey and a mare, is sterile; it is unable to produce viable gametes because the chromosomes inherited from its parents do not pair and cross over correctly during meiosis.

iii. Hybrid is healthy and fertile, but less fit or infertility appears in later generations as witnessed in laboratory crosses of fruit flies, where the offspring of second-generation hybrids are weak and usually cannot produce viable offspring.

1.3 Speciation by polyploidy

Polyploidy is when the number of chromosomes in a cell becomes doubled. This can happen by a mutation that simply makes two copies. It can also happen when the chromosomes from two different species are mixed in hybridisation, making a polyploidy organism. The resulting organism is not capable of interbreeding with other species. Most angiosperm plants exhibit triploidy and tetraploidy, or even octoploidy e.g. in strawberry plants and sugar cane. Polyploidy has been observed in insects, fish, amphibians, reptiles. About half of angiosperm species seem to have originated by polyploidy. Polyploid plants are often larger and have other accentuated characteristics, making them useful in agriculture and horticulture. Polyploidy can be artificially induced in plants by botanists and horticulturalists, e.g. with the chemical colchicine, which prevents chromosomes from separating during mitosis. Relatively few animal species are thought to have originated this way, because not all animals can self-fertilize or reproduce asexually. Animal species like weevils, bagworm moths and flies, however, seem to have arisen by polyploidy.

There are two types of polyploidy. Polyploids whose chromosomes originate from the same ancestral species are called autopolyploids. Polyploids that result from hybridization events between different species are called allopolyploids. Allopolyploids are significantly more common than autopolyploids. Being more distributed in plants, polyploidization is considered an important mechanism for initiating speciation in plants. Under the assumption that any plant with a haploid number of chromosomes greater than 14 is polyploid, Verne Grant estimated that 58% of monocots and 43% of dicots are the descendants of ancestors that underwent polyploidy. Grant goes so far as to say that polyploidy "is a characteristic of the plant kingdom"

Some examples:

i. The species *Gilia transmontana* of the Mojave desert in California turned out to be a hybrid of *Gilia minor* and *Gilia clokeyi*. It has as many chromosomes as the other two combined, and its flowers have an intermediate shape. Since chromosomes are not all the same length, it is possible to even tell which of the chromosomes in *G. transmontana* came from which of the two parental ancestors.

ii. Through use of a chemical, colchicines to encourage polyploidy, many species of common garden plants - tulips, crocuses, irises and primroses, have been created artificially.

iii. Humans have deliberately re-created wild plants. Example: the mint *Galeopsis tetrahit*, which was made artificially by hybridising *G. pubescens* and *G. speciosa*. The artificial hybrid was identical to the wild plant and could breed freely with it.

Do the following activity to see your progress. Answer the questions.

Activity 1.3

1. Define

   i. Reproductive isolation

   ....

   ....

ii. Ecological isolation

....

....

iii. Hybridisation.

....

....

iv. Polyploidy.

....

....

2. Differentiate the following terms

   i. Mechanical and behavioural isolation.

   ....

   ....

   ii. Hybridisation and Hybrid.

   ....

   ....

3. Explain briefly, how polyploidy may cause the formation of new species.
4. Explain briefly how niche differentiation may cause the formation of a new species.
5. Define the term sympatric speciation .

Unit summary

Summary

In this unit you learned that two general modes of speciation are distinguished by the way gene flow among populations is initially interrupted. In Allopatric speciation, geographic separation of populations restricts gene flow. In sympatric speciation, speciation occurs in geographically overlapping populations when biological factors, such as chromosomal changes and non random mating, or genetic drift reduce gene flow. Therefore, speciation can take place with or without geographic separation. You now know that new species can be formed either through Allopatric (geographic) speciation or through sympatric speciation. Reproductive isolating mechanisms are either prezygotic or postzygotic. These mechanisms ensure that species remain distinct in nature. Ecological isolation can be prezygotic or postzygotic. Speciation results in the splitting of an ancestral species into two (or more) descendent species. Most plants form new species by polyploidy.

Assignment

Assignment

You will get this separately.

Assessment

Assessment

1. Would you expect to see greater intrinsic or extrinsic postzygotic isolation between two species that recently arose through sympatric isolation? Explain.

2. Differentiate Allopatric and Sympatric speciation
3. i. What does it mean to be sister species?

   ii. Identify the sister species from the phylogenetic tree below

A C

Z F

4. Explain the extent of gene flow between diverging populations as they gradually attain species status.

Unit 2

Natural Selection

2.0 Introduction

A process in nature in which organisms possessing certain genotypic characteristics that make them better adjusted to an environment tend to survive, reproduce, increase in number or frequency, and therefore, are able to transmit and perpetuate their essential genotypic qualities to succeeding generations. So in natural selection, the heritable characteristics or traits which increase the chances of survival and reproduction of an organism are favored, while those traits that are less beneficial are not favored. Originally proposed by Charles Darwin Natural selection is one of the cornerstones of modern biology. The term was introduced by Darwin in his influential 1859 book *On the Origin of Species*. It is the process that results in the evolution of organism, along with mutation, migration, and genetic drift. Natural selection is a contrast to artificial selection, in which humans intentionally choose specific traits considered desirable and systematically favor them for reproduction. In natural selection there is no intentional choice of traits.

Upon completion of this unit you will be able to:

Outcomes

- *Explain* the process of natural selection.
- *Cite* evidence of natural selection.
- *Discuss* the main points of Darwin's Theory of evolution.
- *Explain* effect of natural selection on the frequency of traits.
- *Discuss* natural selection types.

Terminology

Natural selection: Ability of an organism to survive and leave the most reproducing offspring.

Microevolution: Changes in a population due to adaptation

Macroevolution: Broad pattern of evolution over time which occur above the species level

Fitness: Potential for survival

2.1 Theory of Natural Selection

Since Natural selection is the evolutionary process which selects the variation(s) of organisms best suited for a particular environment, natural selection and its evolutionary consequences provide a scientific explanation for the fossil record of ancient life, as well as for the molecular and structural similarities observed among the diverse species of living organisms. Natural selection is therefore a process in nature in which organisms possessing certain genotypic characteristics that make them better adjusted to an environment tend to survive, reproduce, increase in number or frequency, and therefore, are able to transmit and perpetuate their essential genotypic qualities to succeeding generations. So in natural selection, the heritable characteristics or traits which increase the chances of survival and reproduction of an organism are favored, while those traits that are less beneficial are not favored. Originally proposed by Charles Darwin, natural selection is the process that results in the evolution of organism.

2.1.1 Components of natural selection

i. **Variation** all life forms vary genetically within a population.
ii. **Inheritance** as genetic traits are inherited from parents and passed on to offspring.
iii. **Selection** is necessary since organisms with traits that are favourable to their survival and reproduction, are more likely to pass on their genes to the next generation. This is due to the fact that these organisms are better adapted to their environment physiologically, behaviourally and physically (**Taylor** *et al*, 1997).
iv. **Time.** Evolutionary change can happen in a few generations but major change like speciation often take many thousand generations.

2.1.2 Process of natural selection

i. **Overproduction**:

Within a population more offspring are born than can possibly survive.

ii. **Competition:**

Since the number of individuals in a population tends to remain constant from generation to generation due to limited resources, a struggle for survival occurs.

iii. **Survival of the Fittest:**

The individuals who survive are the ones best adapted to exist in their environment because they possess **variations** that best suit them to their environment. This genetic variability within a species is chiefly due to mutation and genetic recombination. The variation of organisms within a species increases the likelihood that at least some members of the species will survive under changed environmental conditions. Due to mutations, individual may have the advantage beyond the environmental challenges. Individual with this mutation may have better adaptation to the environment than others. For an example, the superior trait will help to escape from predators running faster than other individuals. They can reproduce more than other individuals and the trait will pass to the second generation and the evolving of new species happens. The frequency of the new trait will increase in the genome and this process is called natural selection or survival of the fittest organisms.

iv. **Reproduction:**

Variations act to either assist or hinder individuals in their struggle for survival. The best adapted individuals survive and reproduce, passing on the favourable variations to their offspring. As time and generations continue, these adaptations are passed on and new species may evolve from a common ancestor.

Small differences between parents and offspring can accumulate in successive generations so that descendants become very different from their ancestors. We shall look at variations in depth later.

2.1.2 Fitness

Fitness is important for natural selection to occur. Fitness refers to the potential for survival. Generally, individuals that are more "fit" have better potential for survival, "survival of the fittest". Modern evolutionary theory defines fitness not by how long an organism lives, but by how successful it is at reproducing. For an organism that lives half as long as others of its species, but has twice as many offspring surviving to adulthood, its genes will become more common in the adult population of the next generation. This organism is more fit than the others. The fitness of a particular genotype corresponds to the average effect on all individuals with that genotype. Very low-fitness genotypes cause their bearers to have few or no offspring on average. Fitness also depends very much upon the environment.

Examples:

i. Sickle-cell anaemia.

Conditions like sickle- cell anaemia may have low fitness in the general human population, but because the sickle-cell trait confers immunity from malaria, it has high fitness value in populations that have high malaria infection rates.

ii. Antibiotic resistance in microorganisms.

Since the discovery of penicillin in 1928, antibiotics have been used to fight bacterial diseases. Resistance to antibiotics is increased through the survival of individuals that are immune to the effects of the antibiotic, whose offspring then inherit the resistance, creating a new population of resistant bacteria.

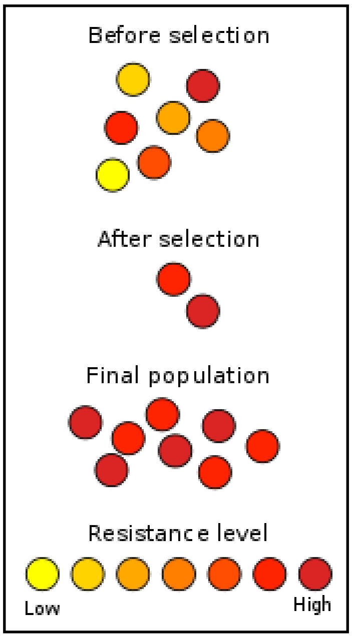

Figure 2.1 Selection in Antibiotic resistance

So, you can see that natural selection acts on an organism's phenotype, or observable characteristics, but it is the organism's genotype that is inherited. The phenotype is the result of the genotype and the environment in which the organism lives. Therefore, we can say that natural selection occurs when:

- There is variation among individuals within a population in some trait and
- This variation is heritable and
- Variation in this trait is associated with variation in fitness.

These successful variations accumulate over the generations as the organisms are exposed to population pressure.

Answer the following questions before moving on to the next section.

Activity 2.1

1. State the stages of natural selection.

   ....
   ....
   ....

2. What is fitness?

   ....
   ....

3. What conditions favour natural selection?

   ....
   ....
   ....

You can now go on to study the next sections.

2.1.3 Genetic basis for natural selection

The origins of variation within a population are mutation and random assortment of chromosomes during *meiosis*. These mechanisms form the genetic basis for natural selection. Therefore without variation within a population, there could be no natural selection - the population would either survive or die as minor environmental changes were encountered, since all members of the population would be genetically identical and all would be equally well or badly equipped to deal with the changes.

Therefore, when natural selection is described as the varying success in reproduction of different phenotypes which in turn are a result of their interaction with the environment, then, unless there are different phenotypes in a population, there can be no natural selection.

2.1.4 Types of natural selection

When some component of a trait is heritable, selection will alter the frequencies of the different alleles, or variants of the gene that produces the variants of the trait. Selection can be divided into three classes, on the basis of its effect on allele frequencies in a population.

a) Directional selection

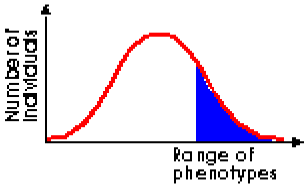

Figure 2.2: One extreme phenotype favoured.

Directional selection, shown **figure 2.2** above, occurs when a certain allele has a greater fitness than others, resulting in an increase of its frequency. This process can continue until the allele is 'fixed' and the entire population shares the fitter phenotype. Directional selection shifts the overall makeup of the population by favouring one extreme phenotype, like when the environment undergoes a marked change. The individuals at one end of the distribution do especially well, and so the frequency distribution of the trait in the subsequent generation is shifted from where it was in the parental generation.

Examples:

i. Industrial melanism/ peppered moth
ii. The illustration on antibiotic resistance is an example of directional selection.

iii. The long neck of the giraffe may have evolved in this way due to shortage of food supply hence the tall individuals could reach tops of trees to feed, survived and passed on their traits for tallness to the next generations.

b) **Stabilizing selection**

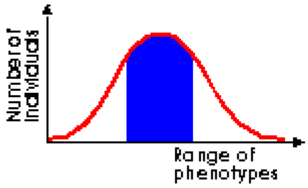

Figure 2.3: Extreme variants removed

Refer to **c** of **figure 2.3** above. Removal of extreme variants from both ends of the frequency distribution in a population reduces the trend towards phenotypic variation and maintaining the status quo. This occurs where an environment is itself stable, it is not changing. Probably this is the most common form of natural selection. A real-life example is that of birth weight in humans as shown in **Figure 2.4** below.

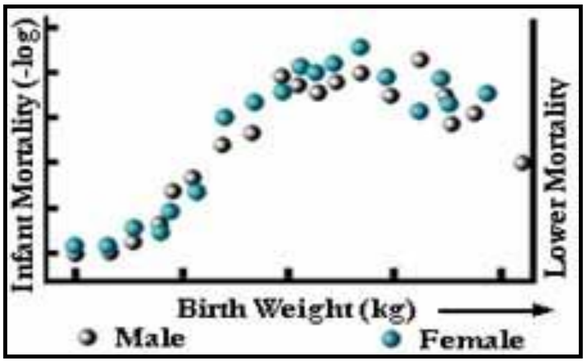

Figure 2.4: Stabilizing selection on birth weight in humans.

c) **Disruptive or diversifying selection**

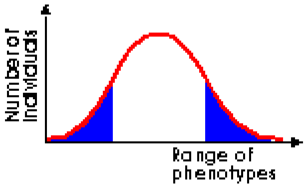

Figure 2.5: Two extreme phenotypes favoured.

Both extremes of the traits are favored at the expense of intermediate varieties. This is uncommon; it suggests a mechanism for species formation without geographic isolation. Disruptive selection favours genotypes that depart from the average in either direction that is, the opposite of over dominance. If the environment of the species contains two different features like in background colour - light/shade, two different phenotypes have a selective advantage, depending on location. This results in a bimodal distribution of trait values. Therefore disruptive selection favours the maintenance of variation in the alleles. **Example:** Evolution of Darwin's finches where as a result of different sized beaks, these birds eat different types of food (**Kent**, 2000).

2.1.5 Natural selection in life stages

Natural selection occurs at every life stage of an individual. An individual organism must survive until adulthood before it can reproduce, and selection of those that reach this stage is called *viability selection*. In many species, adults must compete with each other for mates via sexual selection, and success in this competition determines who will parent the next generation. When individuals can reproduce more than once, a longer survival in the reproductive phase increases the number of offspring. This is called *survival selection*.

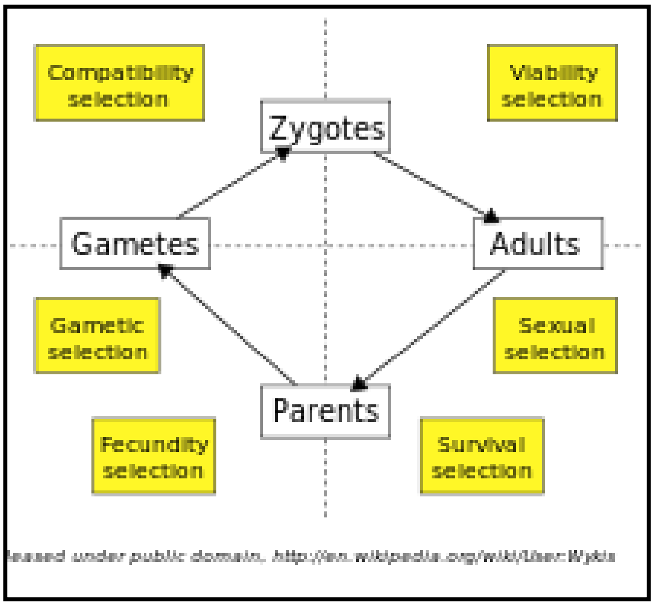

Figure 2.6: Selection during the life stages of sexually reproducing organisms.

Balancing selection

A number of forms of balancing selection exist, which do not result in fixation, but maintain an allele at intermediate frequencies in a population. This can occur in diploid species, that is, species that have homologous pairs of chromosomes, when heterozygote individuals, who have different alleles on each chromosome at a single genetic locus, have a higher fitness than homozygote individuals that have two of the same alleles. This is called heterozygote advantage or overdominance. Balancing selection can occur through frequency-dependent selection, where the fitness of one particular phenotype, depends on the distribution of other phenotypes in the population.

Example:

Malarial resistance observed in heterozygous humans who carry only one copy of the gene for sickle cell anaemia.

2.1.6 Polymorphism

This is the existence of two or more forms of the same species. It is important in natural selection.

i. Balanced or stable polymorphism

This is a situation where the different forms of the same species coexist in the same population in a stable environment. The genetic frequencies are at equilibrium since they have an equal selective advantage. They are constant in a particular generation.

Example:

- Male and female sexes in plants and animals.
- Human blood groups
- Red-green colour blindness

ii. Transient polymorphism

These are morphs or different forms found in a population which is undergoing strong selection pressure, such that one form is slowly or gradually replacing the other.

Example:

‘Industrial melanism is a phenomenon that affected over 70 species of moths in England. It has been best studied in the peppered moth, Biston betularia. Prior to 1800, the typical moth of the species had a light pattern. Dark colour or melanic moths were rare. During the Industrial Revolution, soot and other industrial wastes darkened tree trunks and killed off lichens. The light-colour morph of the moth became rare and the dark morph became abundant. In 1819, the first melanic morph was seen; by 1886, it was far more common - illustrating rapid evolutionary change. Eventually light morphs were common in only a few locales, far from industrial areas. The cause of this change was thought to be selective predation by birds, which favored camouflage coloration in the moth. In the 1950's, the biologist Kettlewell did release-recapture experiments using both morphs. By observing bird predation, he confirmed that conspicuousness of moth greatly influenced the chance it would be eaten'.

Figure 2.10 a. White moth b. Black/dark moth

Now answer the following questions.

Activity 2.1

1. Name and explain types of natural selection.

   ....

   ....

2. What is polymorphism?

   ....

   ....

3. What conditions are prerequisite to natural selection?

   ....

   ....

2. 2 Population genetics

In section 1 we saw that natural selection is the gradual process by which biological traits become either more or less common in a population, as a function of the effect of inherited traits on the differential reproductive success of organisms interacting with their environment. Individuals with certain variants of the trait may survive and reproduce more than individuals with other, less successful, variants. Therefore the population evolves.

2.2.1 Population pressure

A population pressure is a circumstance that acts to make it harder for organisms to survive. The process of natural selection can be speeded up by strong population pressures. There's always some kind of population pressure, but events like floods, droughts or new predators can increase it. Under high pressure, more members of a population will die before reproducing. This means that only those individuals with traits that allow them to deal with the new pressure will survive and pass along their alleles to the next generation. This can result in drastic changes to allele frequencies within one or two generations. Sometimes an organism reaches a state of equilibrium in which its traits are very well-suited to its environment. When nothing happens to exert strong population pressure on that population, natural selection favors the allele frequency already present. When mutations cause new traits, natural selection removes these traits out because they're not as efficient as the others or they are deleterious.

Remember the Hardy-Weinberg Principle in module 3 of BIO 360. You learnt that evolution takes place if there are changes in the frequencies of alleles within a population. Natural selection, along with genetic drift, and gene flow are the mechanisms that cause changes in allele frequencies over time. When one or more of these forces are acting in a population, the population violates the Hardy-Weinberg assumptions, and evolution occurs.

2.2. Factors affecting gene frequency

Gene frequencies tend to remain constant from generation to generation when disturbing factors are not present. Factors that disturb the natural equilibrium of gene frequencies include mutation, migration (or gene flow), random genetic drift, and natural selection. A mutation is a spontaneous change in the gene frequency that takes place in a population and occurs at a low rate. Migration is a local change in gene frequency when an individual moves from one population to another and then interbreeds there. Random genetic drift is a change that takes place from one generation to another by a process of pure chance. Mutation, migration, and genetic drift alter gene frequencies without regard to whether such changes increase or decrease the likelihood of an organism surviving and reproducing in its environment. They are all random processes. In natural selection, those variations in the genotype that increase an organism’s chances of survival and reproduction are preserved and multiplied from generation to generation at the expense of less advantageous ones. Evolution often occurs as a consequence of this process. Therefore, natural selection may arise from differences in survival, in fertility, in rate of development, in mating success, or in any other aspect of the life cycle. All such differences result in natural selection to the extent that they affect the number of progeny an organism leaves.

Natural selection moderates the disorganizing effects of these processes because it multiplies the incidence of beneficial mutations over the generations and eliminates harmful ones, since their carriers leave few or no descendants. Natural selection enhances the preservation of a group of organisms that are best adjusted to the physical and biological conditions of their environment and may also result in their improvement in some cases.

2.2.1 Hardy-Weinberg Equilibrium

Makes the following assumptions that

i. allele frequency pattern of a population is $p + q = 1$

ii. Genotype frequency of a population is $(p + q)^2 = p^2 + 2pq + q^2 = 1$

1. Individuals with each genotype must be as reproductively fit as those of any genotype in the population.
2. The population must consist of a large number of individuals.
3. Random mating must occur throughout the population.
   Therefore the frequency of allele variations in a population and the genotype frequencies will remain constant from generation to generation, in an infinitely large interbreeding

population in which mating is random; there is no selection, migration or mutation.

2.2.2 Role of natural selection

Natural selection is the most prominent agent in determining the relative frequency of alleles in a population. It differentiates between phenotypes in a population with respect to their ability to produce offspring, because one phenotype may better survive endemic attacks of parasites or predation than another; or it may penetrate new habitats more efficiently than another, or mate more efficiently than another. This affords one genotype greater representation than another. If this selective process continues, over many generations, allelic frequencies change significantly and the potential for evolutionary change rises. The natural selection process while acting on the total phenotype only influences the heritable portion of the phenotype.

2.2.3 Parameters of natural selection

i. Survival rate

ii. Relative fitness W

iii. Selection coefficient (s) = 1 – W

Where ‘W’, reflects the chances of an organism’s survival and reproductive success, in a particular environment.

‘s’ is the chance of an organism’s failure to survive and reproduce due to selection.

S = 1-W

Is we consider data from a population with a single gene locus, defined by A and a alleles, assuming incomplete dominance, so as to distinguish A/a heterozygote phenotypes from A/A and a/a homozygotes.

If the numbers of each of the phenotypes in a given generation immediately before and after a selective agent like a parasite are determined, it is possible to calculate the Relative fitness and Selection Coefficients from the data in the same generation of a population.

Example:

	A/A	A/a	a/a
Before selection	4100	5000	2200
After selection	3900	4000	1200

a) Survival rate A/A = 3900/4100 = 0.95

A/a = 4000/5000 = 0.80

a/a = 1200/2200 = 0.55

b) Relative fitness W WAA =0.95/0.95 = 1.00

Compared with A/A's maximum survival rate of 0.95

WA/a = 0.80/0.95 = 0.84

Wa/a = 0.55/0.95 = 0.58

c) Selection Coefficients s $S_{A/A}$ =1- $W_{A/A}$ = 0

SA/a = 1-Wa/a =0.16

Sa/a =1-Wa/a = 0.42

The genotype with the largest survival rate is defined as the fittest, and it is used as the standard for the relative fitness (W) of all other genotypes. Just as 'W' reflect the chances of an organism's reproductive success. Hence, ‘s’ reflects the chances of its reproductive failure due to selection.

Activity 2.3

1. Define

a) Relative Fitness

b) Survival rate

c) Selection pressure

2. What conditions favor maintaining the Hardy-Weinberg equilibrium in a population?

3. How may the Hardy-Weinberg equilibrium be changed?

Unit Summary

In this unit you learned about the process of natural selection and how it affects the process of change in a population. Natural selection pressures operate on the heritable variation which exists within populations of organisms, which must in turn produce more progeny than can survive, and these offspring vary in their ability to survive and reproduce.

Unit 3

Variation

3.0 Introduction

The differences observed between individuals of the same species are referred to as variation. They may be caused by genetic differences, environmental influence or a combination of the genetics and environment of organisms.

Upon completion of this unit you will be able to:

Outcomes

- *Discuss* types of variation.
- *Explain* causes of variation.
- *Relate* variation to speciation.

3.1 Types of variation

Variations have been defined as the differences in characteristics shown by organisms belonging to the same natural population of species (Taylor D. J. *et al*. 1977). You will notice that even among humans there are some differences in the appearance or phenotypes or physical characteristics. Variation exists within all populations of organisms. This occurs partly because random mutations occur in the genome of an individual organism, and these mutations can be passed to offspring. Throughout the individuals' lives, their genomes interact with their environments to cause variations in traits. Individuals with certain variants of the trait may survive and reproduce more than individuals with other, less successful, variants.

There are two basic types of natural variation among living organisms.

i. Continuous variation

These are characteristics that show a gradation from one extreme to another without any break. They show intermediates between any two extremes. Although these phenotypes are a product of genetic factors, they are modified by environmental factors.

Example:

Height, among humans

ii. Discontinuous variation

These characteristics show clear cut differences, there are no intermediates.

Example:

Sex, in animals and plants.

The discontinuous variations are controlled by one or two major genes with two or more allelic forms. Environmental conditions have no effect on their phenotypic expression.

Natural variation occurs among the individuals of any population of organisms. Many of these differences do not affect survival, but some differences may improve the chances of survival of a particular individual.

Example: A rabbit that runs faster than others may be more likely to escape from predators, and algae that are more efficient at extracting energy from sunlight will grow faster. Something that increases an animal's chances of survival will often also include its reproductive rate since an individual organism's phenotype results from both its genotype and the influence from the environment it has lived in. A large number of the variation in phenotypes in a population is caused by the differences between their genotypes. According to the modern evolutionary synthesis, evolution is the change over time in this genetic variation. The frequency of one particular allele will become more or less prevalent relative to other forms of that gene. Variation disappears when a new allele reaches the point of **fixation**, when it either disappears from the population or replaces the ancestral allele completely.

3.2 Sources of variation

Natural selection will only cause evolution if there is enough **genetic variation** in a population. You are already aware that the *Hardy-Weinberg principle* provides the solution to how variation is maintained in a population with Mendelian inheritance. The frequencies of alleles (variations in a gene) will remain constant when there is no selection, mutation, migration and genetic drift.

Variations come from the process of **meiosis** and **fusion of gametes** during fertilization.

Recall the following events from your studies on what happens to the genes, chromatids and chromosomes during the process of meiosis.

i. As a result of crossing over of genes between chromatids of homologous chromosomes during meiosis. New linkage groups are formed and they are a major source of genetic recombination of alleles, hence variations.

ii. During independent assortment of metaphase 1 and consequent random orientation of the chromatids, further orientation in metaphase 11, and anaphase 11 also give rise to a large number of different combinations of chromosomes in the gametes, hence variations as well.

iii. Fusion of any male gamete with any female gamete is a random process. There is a random fusion of gametes. This also forms another source of variation.

In these sources of genetic variation, the gene-reshuffling that takes place acts as a basis for continuous variation.

Mutation - Mutations are changes in the amount or arrangement of DNA (Chromosomal mutation/chromosome aberration) or structure of DNA of a cell's genome (gene mutation or point mutation). Gene mutations can be duplication, insertion, deletion, inversion or substitution of bases in the genes. Mutation enables new alleles to arise within a population. Hence new species arise. They are the major source of all genetic variation. When a mutation takes place it causes the following to take place;-

i. No effect on the DNA.
ii. Alter the product of a gene, or
iii. Prevent the gene from functioning.

Mutations cause changes in the genotype hence can be inherited. So, the appearances of population characteristics can change/ new species arise. Mutations in gamete cells are inheritable by the organism whereas those in somatic cells can only be passed on /inherited by the daughter cells of mitosis.

From evidence of studies done on the fruit fly *Drosophila melanogaster*, it has been suggested that if a mutation changes a protein produced by a gene, this will probably be harmful, with about 70% of these mutations having damaging effects, and the remainder being either neutral or weakly beneficial.

The rate of mutations is random and spontaneous, but varies from organism to organism.

Migration between populations /gene flow.

Individuals immigrating into a population may introduce alleles never before found in the population. Individuals emigrating from a population may remove alleles that are not found elsewhere in the population.

Gene flow is the exchange of genes between populations and between species. It can therefore be a source of variation that is new to a population or to a species. Gene flow can be caused by the movement of individuals between separate populations of organisms, as might be caused by the movement of pollen between heavy metal tolerant and heavy metal sensitive populations of grasses.

Genetic Drift.

This is the change in allele frequency due to chance and it affects small populations. If a population is small and some random event causes a number of individuals to die then the remaining population may have a different genetic structure by chance. One type of genetic drift occurs when a small number of individuals disperse and colonize a new area, and a new population is produced. This is called the **Founder Effect**. In this case, the allele frequencies in the new population depend on the gene pool of this small number of founding members of the population. Genetic drift may cause gene variants to disappear completely and thereby reduce genetic variation.

Despite the constant introduction of new variation through mutation and gene flow, most of the genome of a species is identical in all individuals of that species. Even relatively small differences in genotype can lead to dramatic differences in phenotype: for example, chimpanzees and humans differ in only about 5% of their genomes. Now answer the following questions.

Activity 3.1

1. Name

a) Types of variation, give examples

…………………………………………………………
…………………………………………………………
…………………………………………………………

b) Differentiate types of variation.

…………………………………………………………
…………………………………………………………
…………………………………………………………

c) Explain role of the following in variation

i. Migration

ii. Mutation

iii. Genetic drift.

iv. How does each of i and iii above act to bring about speciation?

Unit summary

Summary

In this unit you learned about different types of variation, how these are caused and their relationship with speciation.

Assessment

Assessment

1. Define variation
2. Explain causes of variation
3. Discuss relationship of variation with speciation.

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