ZL-101: Biosystematics and Taxonomy

Unit I

- Definition and basic concepts of biosystematics taxonomy and classification.
- History and theories of biological Classification.
- Trends in biosystematics: Chemotaxonomy, cytotaxonomy and molecular taxonomy
- Dimensions of speciation. Species concepts: Typological, Nominalistic and Biological species concepts. Subspecies and other infra-specific categories.

Unit II

- Taxonomic Characters and different kinds.
- Origin of reproductive isolation, biological mechanism of genetic incompatibility.
- Taxonomic procedures: Taxonomic collections, preservation, curetting, process of identification.

Unit III

- Taxonomic keys, different types of keys, their merits and demerits.
- International code of Zoological Nomenclature (ICZN): Operative principles, interpretation and application of important rules: Formation of Scientific names of various Taxa.
- Synonyms, homonyms and tautonomy.

Unit IV

- Evaluation of biodiversity indices.
- Evaluation of Shannon Weiner Index.
- Evaluation of Dominance Index.
- Similarity and Dissimilarity Index.

Suggested Reading Material (All latest editions)

1. M. Kato. The Biology of Biodiversity. Springer.
2. J.C. Avise. Molecular Markers, Natural History and Evolution, Chapman & Hall, New York.
3. E.O. Wilson. Biodiversity, Academic Press, Washington.
4. G.G. Simpson. Principle of animal taxonomy, Oxford IBH Publishing Company.
5. E. Mayer. Elements of Taxonomy.
6. E.O. Wilson. The Diversity of Life (The College Edition). W.W. Northem& Co.
7. B.K. Tikadar. Threatened Animals of India, ZSI Publication, Calcutta.

Practical **Module – I**

- Composition assessment of the taxonomic diversity / biodiversity in a habitat (e.g. grassland, arid land, wet land, etc.).
- Influence of climatic conditions on taxonomic diversity in a given habitat.
- Preparation of models showing the status of certain taxa or species in a particular habitat.

Unit I

- Definition and basic concepts of biosystematics, taxonomy and classification.
- History of Classification
- Trends in biosystematics: Chemotaxonomy, cytotaxonomy and molecular taxonomy
- Dimensions of speciation.
- Species concepts: species category, different species concepts, subspecies and other infra-specific categories.
- Theories of biological classification: hierarchy of categories.

Definition and basic concepts of biosystematics, taxonomy and classification

Biosystematics:

- Systematics: In biology, systematics is the study and classification of living things; in other words, grouping organisms based on a set of rules (or system).
- The science of classifying organisms.
- Thus, biosystematics may be defined as 'taxonomy of living populations'.
- The word systematics is derived from the Latinized Greek word '*systema*' applied to the system of classification developed by Carolus Linnaeus in the 4th edition of his historical book *Systema Naturae* in 1735.

Kinds of Systematics

- Systematics can be divided into two closely related and overlapping levels of classification: **taxonomic** (known as the Linnaean System) and **phylogenetic**.
- Taxonomic classifications group living things together based on shared traits - usually what they look like or what their bodies do.
- For example, animals that lay eggs and have scales we call reptiles, and animals that give births and have fur or hair we call mammals.
- More specifically, all humans share the same characteristics and so belong to a group, or taxon, of the genus *Homo*, and species *sapien*.
- Phylogenetic classifications use the taxonomic names, but further group organisms by how evolutionarily related they are to one another.
- By looking at each organism's genes, we know that gorillas (taxonomic term) are more closely related to humans than they are to cockroaches.

Taxonomy:

- Taxonomy is the theory and practice of identifying plants and animals. In fact, taxonomy deals with the principle involved in the study of classification of organisms.

- It is the functional science which deals with identification, nomenclature and classification of different kinds of organisms all over the world.
- The word 'taxonomy' is derived from the Greek words *taxis* (= arrangement) and nomos (= law) and the term 'taxonomy' was coined by A. P. de Candolle in 1813.

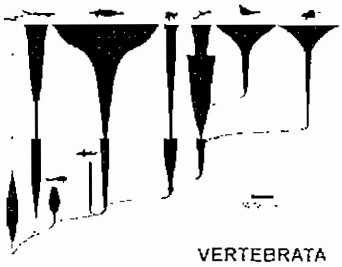
There are several stages of taxonomy such as:

- ***Alpha taxonomy***: In this stage species are identified and characterized on the basis of gross morphological features.
- ***Beta taxonomy***: In this stage species are arranged from lower to higher categories, i.e., hierarchic system of classification.
- ***Gamma taxonomy***: In this stage intraspecific differences and evolutionary history are studied.

- The nomenclatural and taxonomic system for botany introduced by Linnaeus and improved by many generations of later botanists as its first goal to make possible information storage and retrieval concerning plants and plant products.
- While Linnaeus originally believed the systematic pattern he recognized in nature to

divine creation, post-Darwinian botanists have mostly interpreted it as resulting from evolution.

- Many botanical taxonomists of today therefore regard systematics as the art of tracing similarities between taxa, combining them into larger groups, and hypothesizing about their evolution.
- While the number of taxonomic features available to Linnaeus was very limited, the gradual refinement of technical equipment has both widened the scope of morphological studies and facilitated the introduction of ancillary sciences like anatomy, embryology, serology, cytotaxonomy, genetics, palynology, and chemotaxonomy.

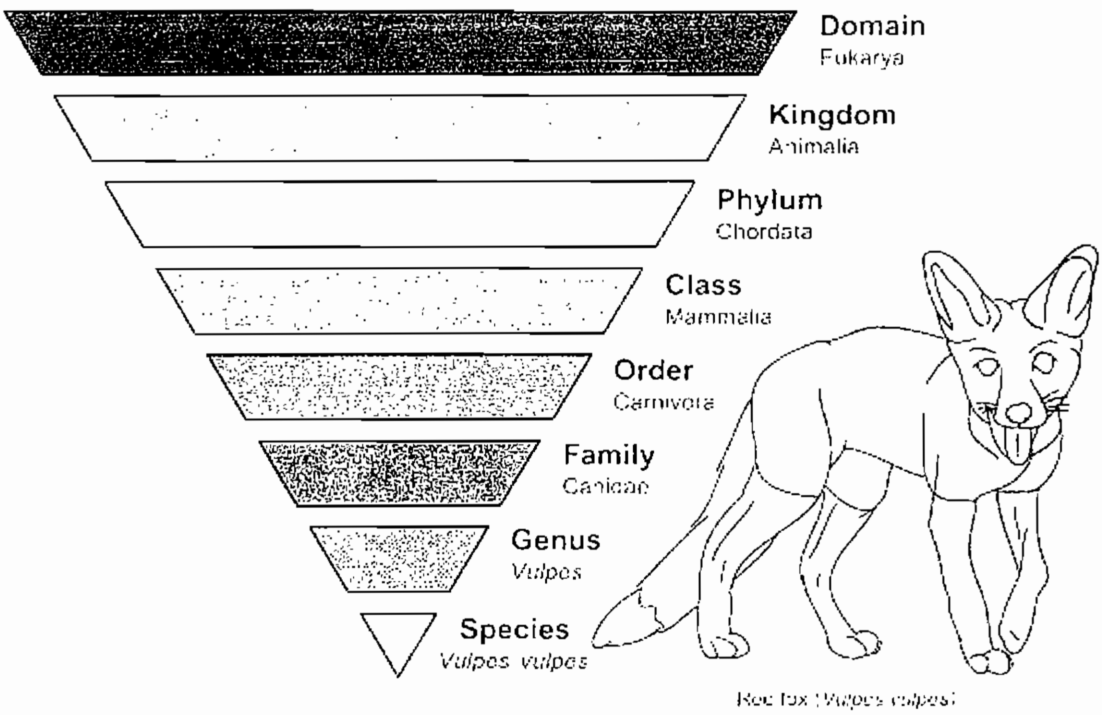


- Those have provided a number of new character sets, the incorporation of which has been facilitated by methodologies such as numerical taxonomy, cladistics and DNA hybridization.

Biological Classification:

Biological classification is a critical component of the taxonomic process. Biological classification uses taxonomic ranks, in order from most inclusive to least inclusive: Domain, Kingdom, Phylum, Class, Order, Family, Genus, and Species.

Rank	Fruit fly	Human	Pea	*E. coli*
Domain	Eukarya	Eukarya	Eukarya	Bacteria
Kingdom	Animalia	Animalia	Plantae	Bacteria
Phylum or Division	Arthropoda	Chordata	Magnoliophyta	Proteobacteria
Class	Insecta	Mammalia	Magnoliopsida	Gammaproteobacteria
Order	Diptera	Primates	Fabales	Enterobacteriales
Family	Drosophilidae	Hominidae	Fabaceae	Enterobacteriaceae
Genus	*Drosophila*	*Homo*	*Pisum*	*Escherichia*
Species	*D. melanogaster*	*H. sapiens*	*P. sativum*	*E. coli*



History of Classification:

The Greeks and Romans

Aristotle (384–322 BC):

In Western scientific taxonomy, the Greek philosopher Aristotle was the first to classify all living things, and some of his groups are still used today, like the vertebrates and invertebrates, which he called animals with blood and without blood. He further divided the animals with blood into egg-bearing and live-bearing, and formed groups within the animals without blood that we recognize today, such as insects, crustacea and testacea (molluscs).

Theophrastus (370–285 BC):

Theophrastus was a student of Aristotle and Plato. He wrote a classification of all known plants, *De Historia Plantarum*, which contained 480 species. His classification was based on growth form. Carolus Linnaeus accepted many of his generic names.

There are two surviving botanical works by Theophrastus – The Enquiry into Plants and On the Causes of Plant Phenomena. In his Causes Theophrastus looks at plant physiology and considers different methods of cultivation. In the Enquiry Theophrastus turns his attention in a more taxonomical direction. In this work he was one of the first authors to attempt to classify plants into different types, dividing them into ‘trees’, ‘shrubs’, ‘undershrubs’ and ‘plants’. These two books give Theophrastus a good claim to the title of ‘the grandfather of botany’.

Dioscorides (40–90 AD):

Dioscorides was a Greek physician and a medic in Roman Army, who travelled widely in the Roman and Greek world to gather knowledge about medicinal plants and wrote *De Materia Medica*, which contained around 600 species. *De Materia Medica* was used in medicine until the 16th century, and was copied several times. One famous copy from the 6th century is kept in Vienna. The classification in his work is based on the medicinal properties of the species.

Plinius (23–79 AD):

Plinius was involved in the Roman army and wrote many books, but the only one that has survived is his ‘*Naturalis Historia*’, a work of 160 volumes, in which he described several plants and gave them Latin names. Many of these names we still recognize, like *Populus alba* and *Populus nigra*, and since Latin was later kept for botanical science, we may call him the Father of Botanical Latin.

Early taxonomists

Until the end of the 16^{th} century, the taxonomic works of ancient Greeks were not replaced. One of the reasons for this was the development of optic lenses, which made it possible to study details in the different species. Collection of specimens became part of the growing sciences, and the emphasis turned from medical aspects to taxonomic aspects.

Caesalpino (1519–1603):

Caesalpino in Italy, who is sometimes called "the first taxonomist". In 1583 he wrote *De Plantis*, a work that contained 1500 species. His classification was based on growth habit together with fruit and seed form, as was that of Theophrastus.

Bauhin (1541–1631) and **Bauhin (1560–1624)**

Two Swiss brothers (Bauhin) wrote the work '*Pinax Theatri Botanici*' in 1623. The work is a listing of 6000 species. The Bauhin brothers included synonymes, which was a great necessity of the time. The Bauhin brothers recognized genera and species as major taxonomic levels. Linnaeus honored the Bauhin brothers Gaspard and Jean in the genus name *Bauhinia*.

John Ray (1627–1705):

John Ray, the English naturalist wrote several important works through his life. His most important contribution was the establishment of species as the ultimate unit of taxonomy. In 1682 he published '*Methodus Plantarum Nova*', which contained around 18000 plant species, a result of a relatively narrow species concept.

He published important works on botany, zoology, and natural theology. His classification of plants in his *Historia Plantarum*, was an important step towards modern taxonomy.

Ray rejected the system of dichotomous division by which species were classified according to a pre-conceived, either/or type system, and instead classified plants according to similarities and differences that emerged from observation. He was the first to give a biological definition of the term species.

In his 1686 History of Plants:

"No surer criterion for determining species has occurred to me than the distinguishing features that perpetuate themselves in propagation from seed. Thus, no matter what variations occur in the individuals or the species, if they spring from the seed of one and the same plant, they are accidental variations and not such as to distinguish a species. Animals likewise that differ specifically preserve their distinct species permanently; one species never springs from the seed of another nor vice versa".

Joseph Pitton de Tournefort (1656–1708):

Joseph Pitton de Tournefort from France constructed a botanical classification that came to rule in botanical taxonomy until the time of Carolus Linnaeus. In 1700, he published *Institutiones Rei Herbariae*, in which around 9000 species were listed in 698 genera. He put primary emphasis on the classification of genera, and many genera were accepted by Linnaeus and still in use today. Tournefort's plant classification was exclusively based on floral characters.

Linnaean era

Starting point of modern taxonomy

For nomenclatural reasons two works of Carolus Linnaeus (1707–1778) are regarded as the starting points of modern botanical and zoological taxonomy: the global flora '*Species Plantarum*', published in 1753 and the tenth edition of '*Systema Naturae*' in 1758 including global fauna. Linnaeus introduced a binary form of species names called "trivial names" for both plants and animals in these books. The trivial names were intended for fieldwork and education, and not to replace the earlier phrase names.

Linnaeus counted 8,530 species of flowering plants in 1753. The simplicity of Linnaeus' trivial names revolutionized nomenclature, and soon binary nomenclature.

Linnaeus published several books that would transform botany and zoology into sciences of their own. Until then, these two disciplines had merely been a fringe of practical medicine. With the works of Linnaeus, botany and zoology transformed into a *Scientia*, a science surrounded by philosophy, order and systems.

Post-Linnaean taxonomy

Natural system emerging in France

One of the few countries in which the Linnaean systematics did not make success was France. Four French scientists emerged that made an impact on future biological sciences.

Georges-Luise Leclerc de Buffon (1707–1788) was a strong critic to Linnaeus work, and he found it wrong to impose an artificial order on the disorderly natural world. His approach was for an evolutionary theory.

Michel Adanson (1727–1806) wrote Familles des Plantes already in 1763. He launched the idea that in classification one should not put greater emphasis on some characters than on others. He critized Linnaeus' works, and considered Tournefort's classification far superior.

Antoine Laurent de Jussieu (1748–1836) changed the system of plants with his *Genera Plantarum* in 1789, in which he launched a natural system based on many characters that came to be a foundation of modern classification. He divided the plants into acotyledons and monocotyledons.

Jean-Baptiste de Lamarck (1744–1829) launched an evolutionary theory including inheritance of acquired characters, named the "Lamarckism".

The French scientific work, the development of anatomy and physiology and improved optical instruments made way for a new era of taxonomy, which was trying to cope with an increasing number of species in a rapidly expanding flora and fauna of the world.

Theories of biological classification: hierarchy of categories.

Biological classification is defined as a process of giving hierarchy of categories by scientific procedure based on features of organisms and arranging them into different groups. The very purpose is to establish the relationship among different organisms and to know about their evolution. Further, to study and include each organism along with its identification and habitat.

Artificial Classification

Artificial Classification uses form, shape as prominent features for grouping organisms. Animals were also classified on basis of red blood cells, habitat such as land, water or air. They were also classified on their basis to fly or not to fly. This system is relatively easy to follow.

Artificial System of Classification has many disadvantages. It relies just on form and shape of organisms and does not take into account other features. So it is difficult to understand the evolution of organism. It leads to misunderstanding of any relationship among organisms. The different types of organisms are arranged in same groups like birds, insects, bats they fly and they are grouped in same criteria. The form and shape of organism is not permanent and it changes with time.

Natural System of Classification

It takes into account multiple features such as anatomy, physiology, pathology, biochemistry, reproduction and cytology to compare the organisms and establish a relationship between them. It overshadows all the disadvantages of artificial system of classification. It helps to understand the evolution of organism by knowing the relationship between them.

The features undertaken in this classification are constant. In this bird, reptiles and mammals are placed in the different groups based on the multiple features. For example humans have 4 chambered hearts, warm blooded nature and denucleated erythrocytes. Fishes have 2 chambered hearts, cold blooded and respire through gills.

Phylogenetic System of Classification

It is defined as a relationship based on the evolutionary aspect of organisms. It is based on Darwin's Concept of Natural Selection. It tells us about the original relationship among organisms. The foremost phylogenetic system of classification was given by Engler and Prantl. They divide the plants into primitive and modern types.

Hierarchy Categories

Taxonomic Hierarchy Categories were also introduced by Linnaeus. They are also known as Linnaean hierarchy. It is defined as sequence of categories in a decreasing or increasing order from kingdom to species and vice versa. Kingdom is the highest rank followed by phylum, class, order, family, genus and species. Species is the lowest rank in the Hierarchy.

The hierarchy has two categories which are obligate and intermediate. Obligate means they are followed strictly and range from kingdom to species as said above. Intermediate are not followed strictly and they are added in obligate list such as subdivision, super family, super class, suborder, subspecies etc.

Species:

Group of population which is similar in form, shape and reproductive features so that fertile sibling can be produced. Some siblings can be sterile when a hybrid is produced. A hybrid can be product of female horse & male donkey (Mule). Or male tiger & female lion known as Tigon. Sexual reproduction is present in eukaryotes. Species is followed by subspecies, varieties and races. These categories are inferior as compared to species.

Genus:

It is defined as group of similar species. But it is not mandatory to have many species. Some genera have only one species known as Monotypic. If there are more than one species it is known as polytypic. For example lion, tiger are quite similar species placed under the genus *Panthera*.

Family:

It is defined as collection of similar genera. For example, cats and leopard are included in the family Felidae.

Order:

One or more than one similar families constitute order. Family felidae are included in the order Carnivora.

Class:

One or more than one order makes a class. Class Mammalia includes all mammals which are bats, rodents, kangaroos, whales, apes and man.

Phylum:

It is a term used for animals while its synonym 'Division' is used for plants. It is a collection of similar classes. Phylum Chordata of animals has class Mammalia along with birds, reptiles and amphibians.

Kingdom:

The top most taxonomic category. Example all animals are included in Kingdom animalia.

Trends in biosystematics: Chemotaxonomy, Cytotaxonomy and Molecular taxonomy.

Chemotaxonomy

The chemotaxonomy or chemical taxonomy is used for the classification of plants on the basis of their chemical constituents. Plants produce thousand types of chemicals. Some of the organic compounds like carbohydrates, fats, proteins, nucleic acids, chlorophylls are required for their basic metabolic processes and found throughout the plant kingdom. These organic compounds are called 'primary metabolites' or 'biomolecules'. These are produced in large quantities and can easily be extracted from the plants.

Many plants, fungi and microbes of certain genera and families synthesize a number of organic compounds which are not involved in primary metabolism (photosynthesis, respiration, and protein and lipid metabolism) and seem to have no direct function in growth and development of plants. Such compounds are called 'secondary metabolites' (secondary plant products or natural products).

These compounds are accessary rather than central to the functioning of the plants in which they are found. These compounds are produced in small quantities only in specific parts of plants and their extraction from the plant is difficult and expensive.

These are derivatives of primary metabolites. Secondary metabolites are not directly involved in the normal growth, development, or reproduction of an organism. They are used for protection and defence against predators and pathogens. Usually, secondary metabolites are specific to an individual species.

The phenolics, alkaloids, terpenoids and non-protein amino acids are the four important and widely exploited groups of compounds utilized for chemotaxonomic classification. These groups of compounds exhibit a wide variation in chemical diversity, distribution and function. The system of chemotaxonomic classification relies on the chemical similarity of taxon.

Examples: Pigments – carotenoid, anthocyanin etc; Alkaloids – morphine, codeine etc; Terpenoides – monoterpene, diterpene, etc; Essential oils – Lemongrass oil; Toxins – abrin, ricin, etc; Lectins – concanavalin A; Drugs – vinblastine, curcumin etc; Polymeric – rubber, gum, cellulose etc.

Cyanogenic glycoside in chemotaxonomy

The cyanogenic glycosides are the compounds responsible for providing defensive mechanism to plants. Plant species have ability to produce hydrogen cyanide (HCN) by enzymatic hydrolysis of cyanogenic glycosides by the process called cyanogenesis. Different amino acid like phenyl alanine, tyrosine, valine, leucine, and isoleucine are precursor for the biosynthesis of cyanogenic glycosides, but they are restricted to families: a cyanogenic glycoside synthesized from leucine commonly occurs in the subfamily Amygdaloideae (almond) and Maloideae (apple) of family Rosaceae.

Cytotaxonomy

It is the branch of biology dealing with the relationship and classification of organism using comparative studies of chromosomes. The structure, number and behaviour of chromosomes is of great value in taxonomy, with chromosome number being the most widely used and quoted character. Chromosome numbers are usually determined at mitosis and quoted as the diploid number (2n). Another useful taxonomic character is the position of the centromere.

The cytotaxonomy is more significant over physiological taxonomy because cytotaxonomy is dealing with the comparative study of chromosome and with this method minute variation among the individuals can be detected. DNA are present in the chromosome and the variation in DNA are responsible for the variation among the individuals, species, genus and so on. The difference in physiological variation are too less among the individuals of same species and other higher taxa.

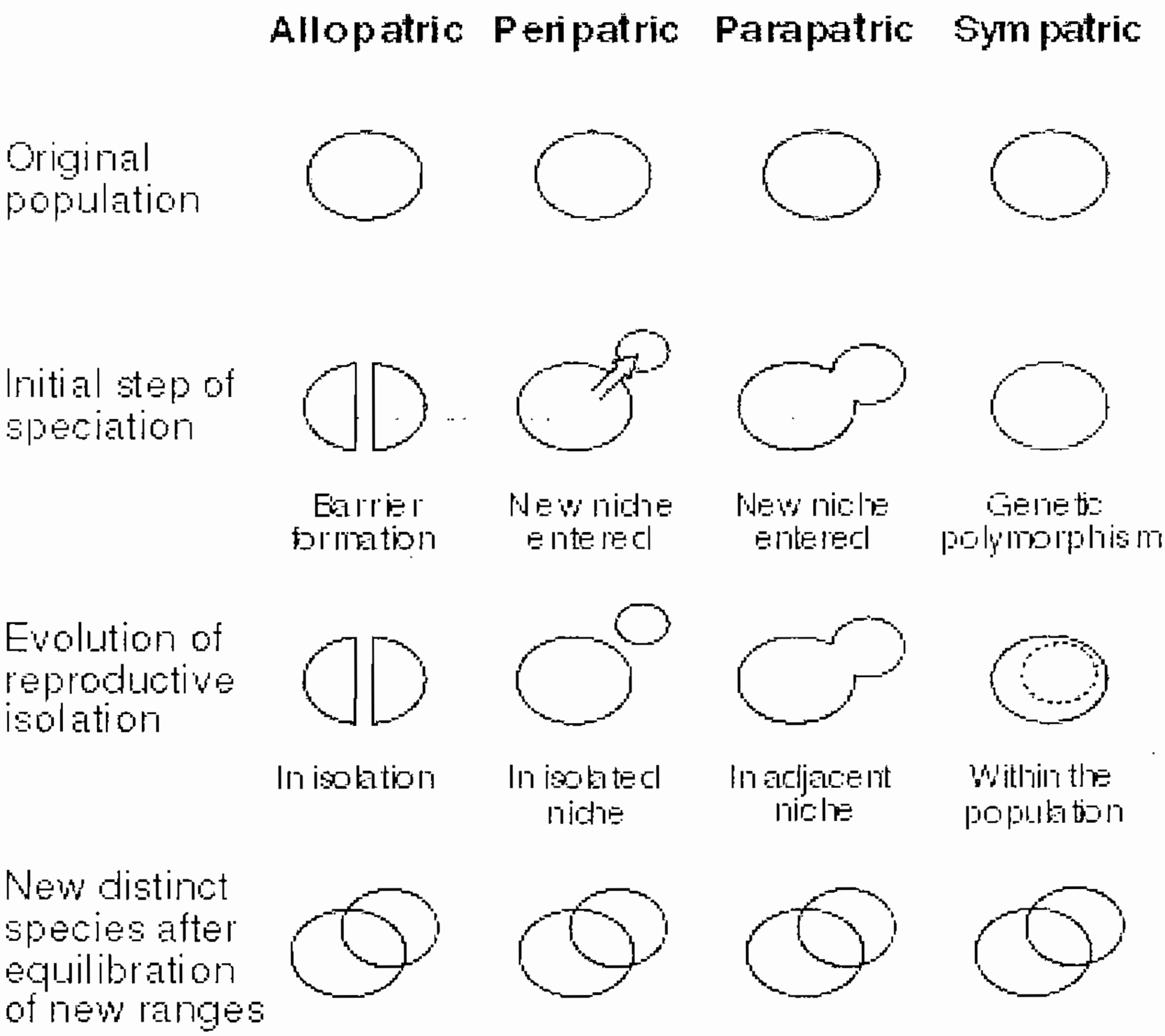
Molecular Taxonomy

Molecular Taxonomy is the classification of organisms on the basis of the distribution and composition of chemical substances in them. Molecular techniques in the field of biology have helped to establish genetic relationship between the members of different taxonomic categories. DNA and protein sequencing, immunological methods, DNA-DNA or DNA-RNA hybridization methods are more informative in the study of different species. The data obtained from such studies are used to construct phylogenetic trees.

Dimensions of speciation

Speciation is the evolutionary process by which biological populations evolve to become distinct species. Charles Darwin was the first to describe the role of natural selection in speciation in his book 'The Origin of Species' (1859).

There are four geographic modes of speciation in nature, based on the extent to which speciating populations are isolated from one another:



allopatric, peripatric, parapatric, and sympatric. All forms of natural speciation have taken place over the course of evolution.

Allopatric

During allopatric speciation, a population splits into two geographically isolated populations (e.g., habitat fragmentation due to geographical change such as mountain formation). The isolated populations then undergo genotypic or phenotypic divergence as: (a) they become subjected to dissimilar selective pressures; (b) they independently undergo genetic drift (variation in the relative frequency of different genotypes in a small population, owing to the chance disappearance of particular genes as individuals die or do not reproduce); (c) different mutations arise in the two populations. When the populations come back into contact, they have evolved such that they are reproductively isolated and are no longer capable of exchanging genes.

Peripatric

In peripatric speciation, a subform of allopatric speciation, new species are formed in isolated, smaller peripheral populations that are prevented from exchanging genes with the main population. It is related to the concept of a founder effect, since small populations often undergo bottlenecks.

Genetic drift is often proposed to play a significant role in peripatric speciation.

Parapatric

In parapatric speciation, there is only partial separation of the zones of two diverging populations afforded by geography; individuals of each species may come in contact or cross habitats from time to time (but behaviours or mechanisms prevent their interbreeding).

Parapatric speciation may be associated with differential landscape-dependent selection. Even if there is a gene flow between two populations, strong differential selection may impede assimilation and different species may eventually develop. Habitat differences may be more important in the development of reproductive isolation than the isolation time.

Sympatric

Sympatric speciation refers to the formation of two or more descendant species from a single ancestral species all occupying the same geographic location. Often-cited examples of sympatric speciation are found in insects that become dependent on different host plants in the same area. However, the existence of sympatric speciation as a mechanism of speciation remains highly debated.

Species concepts: species category, different species concepts, subspecies and other infra-specific categories

The species concept

- Under the currently accepted Biological Species Concept (BSC), species exist only in sexually reproducing organisms as a consequence of the mechanisms of genetic shuffling and recombination during meiosis and in zygote formation.
- Species do not exist in asexually reproducing organisms except as an artificial classificatory convenience.
- The BSC is usually defined as: <u>groups of actually or potentially interbreeding populations in nature which are reproductively isolated from other such groups</u> (Mayr, 1942, 1963).
- By reproductive isolation, evolutionists mean that no gene flow exists between different species, not necessarily that members of different species cannot interbreed and produce hybrids.
- Evolutionists actually use the criterion of lack of gene flow between different species, rather than lack of reproduction.
- Thus, Bock (1986) modified definition of the BSC, namely: *a species is a group of actually or potentially interbreeding populations of*

organisms which are genetically isolated in nature from other such groups.

- The distinction between these two definitions is clarified in the classification of intrinsic isolating mechanisms (Mayr, 1963), as follows:
- 1. Mechanisms that prevent interspecific crosses (<u>premating mechanisms</u>)

  (a) Potential mates do not meet (seasonal and habitat isolation)

  (b) Potential mates meet but do not mate (ethological isolation)

  (c) Copulation attempted but no transfer of sperm takes place (mechanical isolation)

2. Mechanisms that reduce full success of interspecific crosses (<u>postmating mechanisms</u>)

  (a) Sperm transfer takes place but egg is not fertilized (gametic mortality)

  (b) Egg is fertilized but zygote dies (zygote mortality)

  (c) Zygote produces an F1 hybrid of reduced viability (hybrid inviability)

  (d) F1 hybrid zygote is fully viable but partially or completely sterile, or produces deficient F2 (hybrid sterility)

- All of these intrinsic isolating mechanisms serve to prevent exchange of genetic materials between members of different species taxa and achieve genetic isolation.

Species possess three individual sets of properties that separate them from one another:

1. **Genetic coherence**: the members of a species form a genetic community which is genetically isolated from other species. Genetic material from reproduction thus will flow between members of a single species, but not from one species to another under natural conditions. Genetic isolation is maintained by the possession of intrinsic genetic isolating mechanisms.
2. **Reproductive coherence**: the members of a species form a breeding community which is reproductively isolated from other species. Members of one species do not interbreed or attempt to interbreed with members of another species under natural conditions, regardless of the barriers to gene flow between them. Interbreeding between members of different species would be prevented by particular intrinsic reproductive isolating mechanisms.
3. **Ecological coherence**: the members of a species have similar ecological requirements that differ from those of other species. Competition between sympatric members of different species is thus greatly reduced and separated.

- In fully evolved species, all three sets of properties are developed such that the species are completely genetically isolated, completely reproductively isolated and largely ecologically separated from other sympatric species.

Types of species concepts:
Typological species concept

Typological species concept defines as species that "*a group of individuals that differ from other groups by possessing constant diagnostic characters*". Nearly all of the older definitions of the species, including those of Buffon, Lamark and Cuvier refer to the morphological similarities of individuals of the same species.

Typological species concept is also called as Essentialist, Morphological, Phenetic species concept. Typology is based on morphology/phenotype. Still applied in museum research where a single specimen (type specimen) is the basis for defining the species. In paleontology all you have is morphology: typology is practiced and species are defined as *morphospecies* (e.g. snail shells in fossil beds).

Problems: what about sexual dimorphism: males and females might be assigned to different species. Geographic variants: different forms viewed as different species? What about life stages: caterpillars and butterflies? If typology is let run it can lead to over splitting taxa: each variant is called a new species.

Nominalistic species concept

Occan, the proponent of this concept and his followers (Buffon, Bessey, Lamarck, etc.) believed that only individuals exist but did not believe in the existence of species.

Species are man's own creations and have no actual existence in nature. They are mental concept and nothing more. Therefore, such mental concept (i.e. species) of man has no value.

Biological species concept

An entirely new species concept has begun to emerge in the seventeenth century. John Ray believed in the morphological definition of species and his species characterization also contained the germ of *biological species concept*, which considers the reproductive relationship to be a principle species criterion.

The biological species concept was clearly formulated by Jordan, Dobzhansky and Mayr. According to Mayr a species is a group of potentially or actually interbreeding natural population which are reproductively isolated from other such groups.

Dobzhansky added the term gene pool, and defined species as "*a reproductive community of sexually reproducing individuals which share in a common gene pool*". The biological species concept is the most widely accepted.

In the biological species concept, interbreeding among the individuals of the same species and reproductive isolation from other species are the principal criteria.

Evolutionary species concept

Simpson proposed the evolutionary species concept and defined the species as a lineage (an ancestral–descendent sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies.

Mayr has criticized the evolutionary species definition saying that it is the definition of a phyletic lineage, but not of the species. The evolutionary species concept ignores the core of the species problem and thus, Mayr did not accept the evolutionary species concept and he strongly advocated for the biological species concept in spite of certain difficulties in its application.

Subspecies and other infra-specific categories

Subspecies:

Subspecies is actually a category below species. Linnaeus used the term "subspecies" when he classified subgroups of man. He recognised four subgroups such as (i) the American-Indians (*Homo sapiens americanus*), (ii) the Europeans (*Homo sapiens europaeus*), (iii) the Orientals (*Homo sapiens asiaticus*) and the African Negroes (*Homo sapiens afers*).

Early taxonomists applied the term 'variety' indiscriminately for any variation in the population of a species. In the 19th century the term subspecies replaced 'variety' and the term 'variety' is obsolete today.

When a population of a species splits up by natural barriers such as mountains, islands, climate, etc., each isolated group may evolve different characteristic features, so as to become recognizable as a separate geographical race or subspecies.

The scientific name of the race (subspecies) of Indian lion is *Panthera leo persica*, and the name of the African lion (race) is *Panthera leo leo*. The distinguishing features of Indian race are - (i) scantier mane than that of the African race (ii) a longer tassel of hair at the tip of the tail than that of the African race (iii) a well-pronounced tuft of hairs on the elbow joints and (iv) the abdomen bears a fuller fringe of hairs.

Two subspecies (races) of the same species can interbreed if they meet and professional taxonomists can only recognise the differentiating features of the subspecies of a species.

If species which contain two or more than two subspecies, are called ***polytypic*** species and the species which is without subspecies is called ***monotypic*** species. With the establishment of polytypic concept (Beckner, 1959), it is well accepted that some species are distributed in different geographical areas and form different local populations.

It is widely accepted that genotypic variation within allopatric species occurs. It is widely accepted that these populations become different from each other in morphology, biochemical or genotypic variations that help to mark a taxonomic level sufficient to designate them as subspecies.

Types of Species:

(i) Allopatric species:

The two or more related species that have separate geographical ranges are called allopatric species. Examples of such species are Indian lion

(*Panthera leo persica*) and African lion (*Panthera leo leo*).

(ii) Sympatric species:

Two or more species are said to be sympatric when their geographical distributions overlap, though they may segregate into different ecological niche. Examples of this type are the fig-frog (*Rana grylio*) and the gopher frog (*R. areolata*). The former is extremely aquatic, while the latter species is restricted to the margins of swampy areas.

(iii) Parapatric species:

These are the species which have the geographical ranges with a very narrow region of overlap. Example of this type is the flightless Australian grass-hoppers, *Moraba scurra* and *M. viatica*. (Parapatric species are formed in nature mostly through chromosomal rearrangements)

(iv) Sibling species:

Two or more than two closely related species which are morphologically alike but behaviourally or reproductively isolated from each other. Examples are *Drosophila persimilis* and *D. pseudoobscura*. The sibling species can interbreed and are incapable of producing fertile hybrids.

(v) Cryptic species:

The species which are alike on the basis of observed features but are genetically and sexually they are different are cryptic species. There is a confusion between the terms sibling species and cryptic species. <u>The cryptic species are incapable of interbreeding</u>.

(vi) Monotypic species:

When a genus includes a single species but does not include any subspecies, e.g., *Vampyroteuthis*, a vampire squid which is a single monotypic genus and also contains a single species, *V. infernalis* (monotypic species).

(vii) Polytypic species:

When a species contains two or more subspecies, it is called polytypic species. Examples are tiger, *Panthera tigris* which has several subspecies; such as - (i) Indian tiger, *Panthera tigris tigris*, (ii) the Chinese tiger, *P. t. amoyensis*, (iii) the Siberian tiger, *P. t. altaica*, (iv) the Javan tiger, *P. t. sondaica*, etc.

(viii) Endemic species:

The species which are found in a particular region, called endemic species. Usually the species of oceanic islands which are found in a limited geographic area are called endemic species. The Darwinian finches are the endemic species of Galapagos Islands.

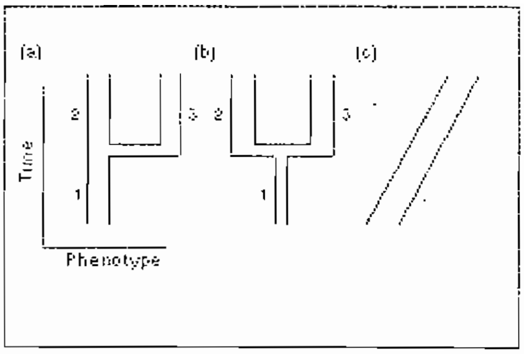
(ix) Agamo species:

Species are those which consist of uniparental organisms. They may produce gametes but fertilization does not take place. They reproduce by obligatory parthenogenesis. In case of bees, wasps, rotifers the haploid eggs develop into haploid individuals and the haploid eggs are not fertilized by sperms.

The species category

- During the process of sexual reproduction, recombination of genetic materials takes place between parental individuals which leads to new combinations of genes in the progeny.
- However, there are many examples which do not come under the biological species category such as hermaphroditism, parthenogenesis, gynogenesis and vegetative reproduction which show uniparental reproduction. There are numerous examples of such uniparental reproduction in invertebrates and vertebrates. Mayr has given a new terminology to such uniparental lineages, i.e. *paraspecies*.
- Most workers have assumed that the species category is the same as the species concept, and hence that the biological species concept (BSC) is the species category. This assumption is invalid because the species category must apply to all organisms, including asexual ones, and the biological species concept applies only to sexually reproducing organisms.
- A broader definition of the species category is needed, concordant with the BSC.
- Defining the species category for all organisms is awkward, but can be summarized as: the fundamental level in the Linnaean hierarchy for

describing the diversity of biological organisms that is based on the biological species concept for sexually reproducing organisms or on the equivalent of the ecological unit of biological species for groups of asexual organisms.



- Survey of taxonomic literature shows that there are a large number of species categories which have been suggested by naturalists, taxonomists and evolutionary biologists from time to time.

Agamo species: Agamo species are those which consist of uniparental organisms. They may produce gametes but fertilization does not take place. They reproduce by obligatory parthenogenesis. In case of bees, wasps, rotifers the haploid eggs develop into haploid individuals.

Cladistic Species: In the cladistic species concept, a species is a lineage of populations between two phylogenetic branch points (between speciation and extinction events). The cladistic concept recognizes species by branch points, independently of how much change occurs between them. Because of this, the two patterns in the figure are cladistically identical: in both there are three species and species 1 gives birth to two new species at the branch point. On the non-temporal species concepts, such as the biological, recognition and ecological species concepts, there are two species in Figure (a) and three in (b).

(a) The ancestral species does not change phenetically (or reproductively or ecologically) after a daughter species evolves. Species 1 and 2 are phenetically identical but cladistically different. (b) The ancestral species changes after the evolution of the new species; species 1 and 2 are both phenetically and cladistically different. (c) Phenetic change in one lineage with no speciation.

Cohesion Species: According to the cohesion species concept (Templeton 1989) a species is the largest delimited population that has internal mechanism, and maintains mutual phenotype cohesion among its members. Phenotype cohesion of a population occurs when mutual similarity observed among the members of the population even when the average appearance of individuals in the population changes in time.

Composite Species: All organisms belonging to an internodon and their descendants until a subsequent internodon (internodon is a set of organisms whose parent-child relations are not split).

E.g. the composite species concept defines a species is a lineage between two temporal occurrence of new characters.

Ecological Species: A lineage which occupies an adaptive zone, minimally different from that of any other lineage in its range and which evolves separately from all lineages outside its range.

Evolutionary Species: A lineage (ancestral-descendent sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies.

Geological concordance (similarity): Population subdivisions concordantly identified by multiple independent genetic units constitute the population units worthy of recognition as phylogenetic taxa.

Genetic Species: Group of organisms that may inherit characters from each other, common gene pool, reproductive community that forms a genetic unit.

Genotypic cluster definition: Clusters of monotypic or polytypic biological entities, identified using morphology or genetics that have few or no intermediates when in contact.

Hennigian species: A tokogenetic community that arises when a stem species is dissolved into two new species and ends when it goes extinct or speciates.

Morphological species: Similar to typological species concept of Linnaeus; species are the smallest groups that are consistently and persistently distinct and distinguishable by ordinary means.

Nominalistic species: Only individuals exist and nothing more. Species have no actual existence in nature.

Nothospecies: Species formed from the hybridization of two distinct parental species.

Phenetic species: A class of organisms that share most of a set of characters. A family resemblance concept is possession of most characters which required for inclusion in a species but not all.

Phylogenetic species: A species is the smallest diagnosable cluster of individual organisms within which there is a parental pattern of ancestry and descent.

The concept of a species as an irreducible group whose members are descended from a common ancestor and who all possess a combination of certain defining, or derived, traits.

Recognition species: The recognition species concept is a concept of species, according to which a species is a set of organisms that recognize one another as potential mates: they have a shared mate recognition system (behavioural, physiological or morphological).

Biological Species: Population of sexually reproducing organisms, interbreeding natural populations isolated from other such groups, depending upon reproductive isolating mechanisms.

Unit II

- Taxonomic Characters and different kinds.
- Origin of reproductive isolation, biological mechanism of genetic incompatibility.
- Taxonomic procedures: Taxonomic collections, preservation, curetting, process of identification.

Taxonomic Characters and different kinds

- Taxonomic character is a distinguishing feature of taxa – a characteristic of one kind of organism which will distinguish it from another kind. Example, serrated leaves may distinguish one species of plant from another and hence called a *character*. Similarly, punctate elytra may differentiate between two species of beetles.
- Mayr et al (1953) define a taxonomic character, as "any attribute of an organism or of a group of organisms by which it differs from an organism belonging to a different taxonomic category (or resembles an organism belonging to the same category)".
- The taxonomic characters can be roughly grouped into:

  a) Morphological characters.
  b) Physiological characters.
  c) Behavioural characters.

d) Ecological and distributional characters.

Morphological Characters

- Structural attributes of organisms at the cellular level or above.
- External, internal, microscopic, including cytological and developmental characters.

Characteristics:

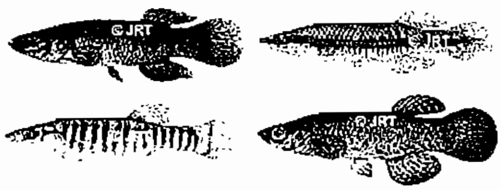
1. Not subject to wide variation among specimens.
2. Not readily modified by the environment.
3. Consistently expressed.
4. Available in specimens you are using.
5. Effectively recorded.

- Characters that do not vary or vary randomly between groups are of no use.

External Morphology:

- Most characters are useful. May be single or complex shape, size, colour, colour pattern, counts of various repeated or comparable structures.

Examples of Color and Color Pattern



Sexual Dimorphism

- Frequently species differ sexually in characters so that the mature individuals appear different. May occur only during breeding season.

Embryonic Character

- Characters have an ontogeny and this may be continuous or discontinuous where there are discrete body forms which undergo metamorphosis. Because of these changes we must use equivalent forms.

- Ontogenetic characters are useful in establishing relationships.

Chromosomes

- Chromosomal changes may accompany or provide speciation, reduced fecundity, and sterile.
- Three levels are analyzed commonly for chromosomes:
- Alpha Karyology - Number and size of chromosomes.
- Beta Karyology - Number and location of centromere to allow for comparison of chromosomes between species.
- Gamma Karyology - Number, centromere & stains for various regions of chromosomes to identify homologous parts of chromosome.
- Chromosome number expressed as haploid or diploid.
- Compare number of metacentrics, acrocentrics and telocentrics.

Physiological characters

Body secretions:

- Morphology, numbers, size and structures of secretory glands. E.g. waxy secretion of scale insects and mealy bugs.

Molecular characters

- Immunological information
- Electrophoretic differences
- Amino acid sequences of proteins
- DNA hybridization
- DNA and RNA sequences

Behavioral characters

- ***Courtship and other ethological isolating mechanisms:***
- Matting and reproducing behaviour of species.
- Help in taxonomic classification.
- Result in reproductive isolation and consequent speciation.
- Living, eating and nesting behaviour.

Ecological characters and distributional characters

- Habit and habitats
- Food and Seasonal variations
- Parasites and hosts
- Geographic characters, General biogeographic distribution patterns
- Sympatric-allopatric relationship of populations

Origin of reproductive isolation: biological mechanism of genetic incompatibility

The origin of reproductive isolating mechanisms

- In the origin and maintenance of race and species, isolation is an indispensable factor and its role and importance have been recognized for a long time.
- Even Lamarck and Darwin pointed out that interbreeding of different populations may result in swamping of the differences acquired during the process of evolutionary divergence.
- During the process of speciation the diverging populations must acquire some means of isolation so that the genes from one gene pool are prevented from dispersing freely into foreign gene pool.
- Reproductive isolating mechanisms prevent exchange of genes between populations by genetically conditioned mechanisms which are intrinsic to the organisms themselves.
- The mechanism of reproductive isolation is a collection of evolutionary, behavioural and physiological processes critical for speciation.
- Thus, the origin of reproductive isolating mechanisms is an important event in the process of cladogenesis (speciation).

Isolating mechanisms:

- The species specific reproductive characteristics prevent different species from fusing. The reproductive isolating barriers maintain the integrity of a species by reducing gene flow between related species.
- Different types of reproductive isolating mechanisms have been studied in *Drosophila* such as gametic isolation, ethological (sexual or behavioural) isolation, hybrid inviability and hybrid sterility.
- Two broad kinds of isolating mechanisms between species are typically distinguished, together with a number of sub-types (Mayr 1970):

Pre-mating isolating mechanisms:

Pre-zygotic isolation mechanisms are the most economical in terms of the natural selection of a population, as resources are not wasted on the production of a descendant that is weak, non-viable or sterile. These mechanisms include physiological or systemic barriers to fertilization.

a) ***Temporal isolation***. Individuals of different species do not mate because they are active at different times of day or in different seasons or difference in the time of sexual maturity or flowering.

b) ***Ecological isolation***: Individuals mate in their preferred habitat, and therefore do not meet individuals of other species with different ecological preferences.

c) ***Behavioural isolation***: Potential mates meet, but choose members of their own species. The potential mates exhibit species specific courtship display.

d) ***Mechanical isolation***: Copulation is attempted, but transfer of sperm does not take place. Mating pairs may not be able to couple successfully if their genitals are not compatible.

Post-mating isolating mechanisms:

a) ***Gametic incompatibility***: Sperm transfer takes place, but egg is not fertilized. The synchronous spawning of many species of coral in marine reefs means that inter-species hybridization can take place as the gametes of hundreds of individuals of tens of species are liberated into the same water at the same time. Approximately a third of all the possible crosses between species are compatible, in the sense that the gametes will fuse and lead to individual hybrids. This hybridization apparently plays a fundamental role in the evolution of coral species. However, the other two-thirds of possible crosses are incompatible.

b) ***Zygotic mortality***. A type of incompatibility that is found as often in plants as in animals occurs when the egg or ovule is fertilized but the zygote does not develop, or it develops and the resulting individual has a reduced viability. This is the case for crosses between species of the frog genus, where widely differing results are observed depending of the species involved.

c)***Hybrid inviability*:** Hybrid embryo forms, but of reduced viability.

d) ***Hybrid sterility*:** Hybrid is viable, but resulting adult is sterile. A hybrid has normal viability but is deficient in terms of reproduction. This is demonstrated by the mule. In all of these cases sterility is due to the interaction between the genes of the two species involved; to chromosomal imbalances due to the different number of chromosomes in the parent species.

Hinnies (male horse x female donkey) and mules (female horse x male donkey) are hybrids. These animals are nearly always sterile due to the difference in the number of chromosomes between the two parent species. Both horses and donkeys belong to the genus *Equus*, but *Equus caballus* has 64 chromosomes, while *Equus asinus* only has 62. A cross will produce offspring (mule or hinny) with 63 chromosomes that will not form pairs, which means that they do not divide in a balanced manner during meiosis.

e)***Hybrid breakdown***. First generation (F1) hybrids are viable and fertile, but further hybrid generations (F2) may be inviable or sterile.

Taxonomic procedures: Taxonomic collections, preservation, curetting, process of identification

Taxonomic collections:

Biological collections are typically preserved plant or animal specimens along with specimen documentation such as labels and notations.

Types of collection

Most biological collections are either dry collections or wet collections. They also may include collections preserved at low temperatures or microscopy collections.

Dry collections

Dry collections consist of those specimens that are preserved in a dry state. Two factors influence decisions about preserving specimens this way:

Rigidity - Some specimens can be preserved naturally (starfish) or artificially with sufficient rigidity to accommodate normal handling. Such specimens often are suitable for dry preservation.

Specific characteristics - Drying may provide the best available means to preserve natural colours (for example, butterflies) or distinguishing features (such as skeletal parts or surface details). Such specimens in a dry state may have great potential for interpretation and research.

Wet collections

Wet collections are specimens kept in a liquid preservative to prevent their deterioration. Certain biological specimens are preserved in a wet form due to: <u>Convenience</u> - an intent to preserve body form and soft parts for a variety of uses. When colour preservation is not critical and dry preservation sacrifices qualities needed for other intended uses, fluid preservation is beneficial.

Biological low-temperature collections

Specimens are maintained at low temperatures to preserve:

- soft parts for various biochemical analyses
- Some algae, Protozoa (especially parasitic strains), Viruses, Bacteria, Bacteriophages, Plasmids
- Animal tissues (dissected organs, muscles),Cell lines
- Blood and blood components (serum, plasma etc)
- Semen, Venom
- Other samples (isolated proteins and nucleic acids, cell suspensions)

Biological microscopy collections:

Scientists preserve certain specimens as microscope preparations to preserve whole or partial organisms for:

- various kinds of microscopic examination

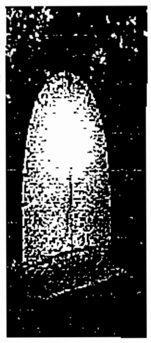
- Biochemical analyses, extraction of DNA.
- Histology
- Karyology
- Scales
- hair

Value of biological collections

Most biological collections are highly valuable for the following reasons. Museums are only place where extinct species are preserved.

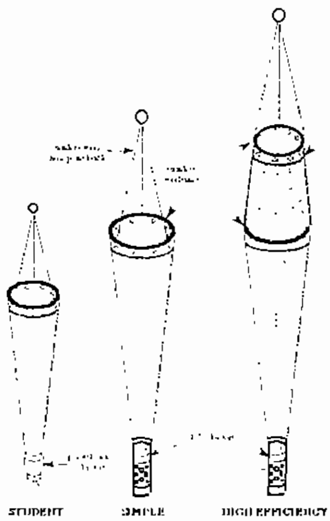
- specimens of special historical value.
- specimens rarely found in any collections.
- Many areas in world are geographically inaccessible. Material from such area are invaluable & are preserved at all costs.



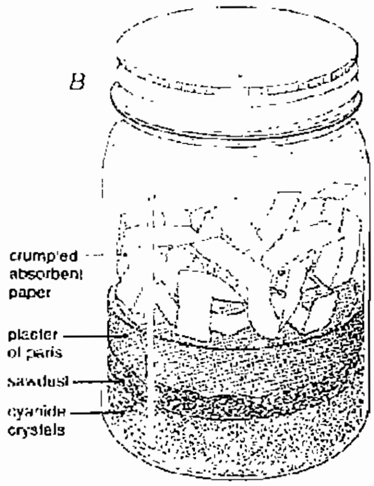


Methods of collections:

- Mist net collection
- Collection of insects light trap.
- Sweeping net.
- Aquatic insects and other arthropods are collected by using dip-nets & plankton nets.

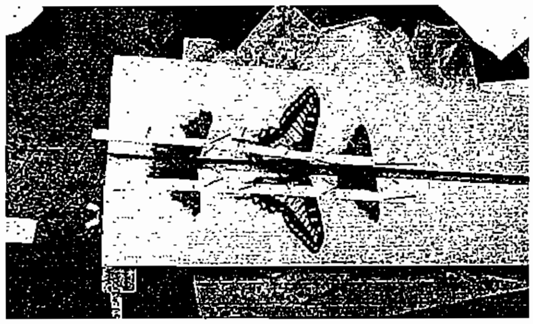


- Trawling and dredging for collecting deep sea animals



Killing Jar:

Spreading tray:



Carcasses or remnants

Carcasses or remnants of dead animals, scat and other biological material found in the wild may be very useful for obtaining data about wild populations. It can no longer be regarded as ethical to kill threatened wild animals for obtaining skins for collections; carcasses of animals found or confiscated from poachers may serve as a better source of material for reference collections. Skeletal material, skulls, owl pellets may be an interesting source of bones, hair samples; reference hair collection of sympatric species,

Fur and hair

After removing the skin from the animal, as much flesh as possible should be removed, but without damaging the skin with hair roots. Then the skin can be dried in the sun, or if necessary, high over a fire, either hung on a line or stretched between pegs. Salting the skin will speed the drying process and temporarily preserve the skin. Areas that still have flesh or fat should be salted thoroughly. Powdered borax can be put on the skin to further preserve it. When the skin is nearly dry, it should be folded with the hairy sides together.

Preservatives and Fixatives

Formalin: Its use will not harm the specimen, is a better preservative than alcohol. It penetrates more rapidly and internal organs remain in better condition. Commercial formalin (40%) should be diluted with ten volumes of water to a 4% solution. 2% formalin with seawater is an excellent quick preservative for small marine specimens.

Alcohol: It is used in zoology, generally 95% ethyl alcohol (white spirits) which may be diluted with distilled water to strengths of 70% and 80%. At least 70% is required for safe storage of material. Alcohol is a valuable preservative for crustacea, polychaeta and echinoderms with bristles or hard-parts.

A teaspoonful of glycerine mixed with alcohol helps to preserve natural colours and to keep integuments flexible.

Alcohol in jars containing preserved specimens should be changed at intervals once or twice a year and evaporation should be guarded against.

One of the most important fixatives for the general collector of invertebrates is Bouin’s fluid, which is excellent for general structural and histological work, and for preservation of animals for dissection. Fixation time is at least 12 hours for a specimen of 1 cc. bulk, correspondingly longer for larger material. There is not much danger of over-fixing. Afterwards specimens should be washed in 70% alcohol, to remove excess picric acid, and stored in 70-80% alcohol.

Formula for Bouin's: 75 parts saturated aqueous picric acid; 25 parts 40% formalin; 5 parts glacial acetic acid.

Preservation by cooling or freezing:

Removal of the skin with insulating fur before cooling or freezing may help to cool the carcass down more quickly. Freezing is not recommended if histological examination is planned.

Storage of the Collection

As the collection grows, the greatest need will be for an orderly storage system, with facilities for quick reference to any container, to field notes and any other information.

It may be desired to have the collection visible for permanent display, and with dried material a set of flat cabinet drawers is best for storage.

Most invertebrates, will be kept in bottles, and sets of tubes or jars can be kept together in a small space by placing them in deep cardboard boxes, conspicuously labelled with serial box numbers.

Containers

Uniform sizes of tubes and jars will be preferred.

Jars should be wide-mouthed, and of clear glass, thick enough to withstand knocks. Non-corrodible tops are preferable to metal caps. Alternatively, wide-mouthed bottles may be stoppered with firm, good quality corks.

Preserving jars with rubber washer lids are ideal for larger specimens.

Specimens as a rule may be put straight into the container.

Labelling

The bulk of the information about a specimen should be entered on the record sheet. Labels attached to the container should include the habitat, locality and date, and the collector's initial.

Alternatively specimen labels can be placed in the preservative within the container. They should then be written on stiff, non-absorbent white card, either in pencil or in indian ink.

Ink labels should be allowed to dry, then steeped for a few minutes in a 3% solution of acetic acid, which effectively sets the ink and prevents "running" when placed in preservative.

Recording of data

- Geographic locality
- Date
- Stage (adult male, female or immature form)
- Altitude or depth.
- Host
- Name of collector and other relevant information

Identification:

Identification of collections may be carried out based on published references and museum specimens.

Curating of Collections

Every taxonomist has to take the responsibility of curating collections. This requires a great deal of expertise, knowledge and clear understanding of the function of different collections.

Preparation of Material

- There are certain materials which are ready for study as soon as collected from the field e.g., bird and mammal skins.
- There are certain insects which should never be placed in alcohol or any other liquid preservative, whereas others are useless when dried.
- Most insects are pinned, and the wings are spread if they are taxonomically important as in butterflies, moths and some grasshoppers.
- Certain invertebrates are to be preserved in alcohol or formalin before their study.

Housing

- Research collections should be housed in fireproof and dustproof buildings.
- Most museums keep their collections in air-conditioned buildings.
- Rapid changes in temperature and humidity are harmful to museum cases and specimens.
- Storage cases should be built to be insect-proof. Photographs and films should be stored in air-conditioned rooms.
- Improperly preserved or inadequately labelled specimens should be eliminated by the curator. The most efficient method for the elimination

of useless material is to ask specialists to pull out such specimens while scrutinizing the material during a revision.

Exchange of Material

- The selecting of material for exchanges and keeping its record is time consuming, so the exchanges are not as popular as they used to be.
- A specialist doing a monograph on a certain genus or family can always borrow material from other institutions and return it after completing his work. Exchanges are sometimes necessary to build up complete identification collections.

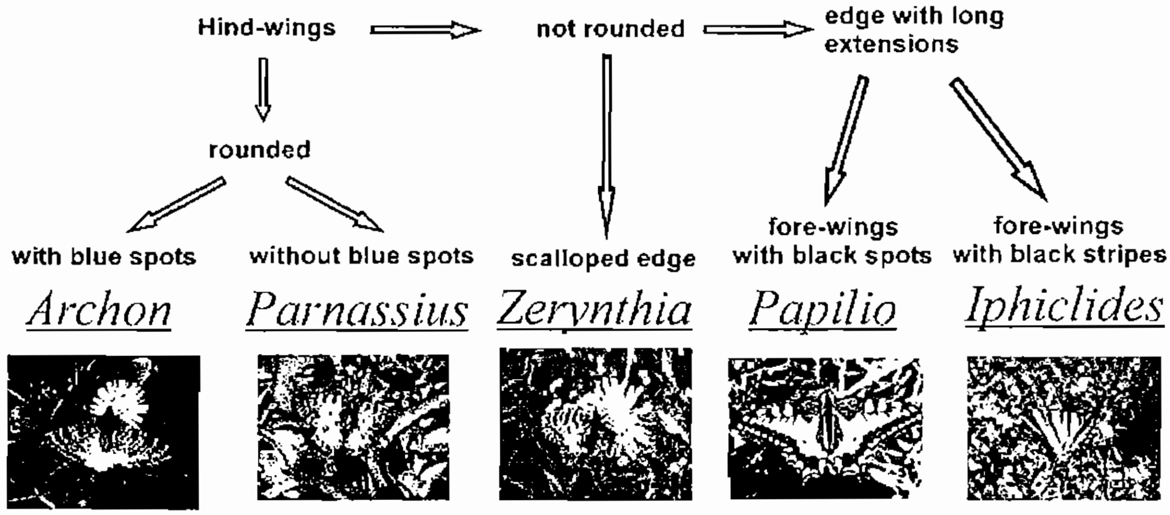
Unit III

- Taxonomic keys, different types of keys, their merits and demerits.
- International code of Zoological Nomenclature (ICZN): Operative principles, interpretation and application of important rules: Formation of Scientific names of various Taxa.
- Synonyms, homonyms and tautonomy.

Taxonomic keys, different types of keys, their merits and demerits

- A key is a device, which constructed properly and used to the identification of unknown species.
- It is a series of contrasting statements required to make comparison and identification.
- The key consists of a series of choices, based on observed features of the specimen. It provides a choice between two contradictory statements resulting in the acceptance of one and the rejection of the other.

Identification key to the genera of the family Papilionidae



- At each point in the decision process, multiple alternatives are offered, each leading to a result or a further choice.
- The alternatives are commonly called **"leads"**, the set of leads at a given point a **"couplet"**. If the entire key consists of exactly two choices at each branching point, the key is called **dichotomous**, otherwise it is described as **polytomous or poly clave**.

Constructive features of taxonomic keys:

1) <u>Constant characteristics</u> rather than variable ones should be used.
2) <u>Proper measurements</u> rather than terms like "**large**" and "**small**" should be used.
3) <u>Characteristics that are generally available</u> to the user of the key rather than seasonal characteristics or those seen only in the field should be used.
4) A <u>positive choice should be made</u>. The term "**is**" instead of "is not" should be used.
5) If possible one should start both choices of a pair with the <u>same word</u>.
6) If possible, <u>different pairs of choices</u> should be started with <u>different words</u>.
7) The descriptive terms should be preceded with the name of the part to which they apply.

Types of Taxonomic Keys

There are basically two types of keys:

A) *Dichotomous* and

B) *Poly clave* (Multiple Access or Synoptic).

A) Dichotomous Keys:

- This is one of the most frequent keys, which are the most common, probably first published by Jean Baptiste-Lamarck in 1778.
- Keys in which the choices allow only two alternative couplets are known as **dichotomous keys**.
- In constructing a key, contrasting characters are chosen that divide the full set of possible species into smaller and smaller groups i.e. the statements typically begin with broad characteristics and become narrower as more choices are required.
- Each time a choice is made, a number of species are eliminated from consideration and the range of possible species to which the unknown specimen may belong is narrowed.
- Eventually, after sufficient choices have been made, their range reduces to a single species and the identity of the unknown species is revealed.
- Couplets can be organized in several forms. The couplets can be presented using numbers (numeric) or using letters (alphabetical). The couplets can be presented together or grouped by relationships.

Example of a numerical key with couplets
1. Seeds round—soybeans 1. Seeds oblong go to—2 2. Seeds white—northern beans 2. Seeds black—black beans

Example of an alphabetical key with same couplets

A. Seeds oblong go to—B
    B. Seeds white—northern beans
    B. Seeds black—black beans
A. Seeds round—soybeans

Types of Dichotomous Keys:

There are two types of dichotomous keys. They differ in the method by which the couplets are organized and how the user is directed to successive choices.

i) Indented Keys (also called yoked):

In indented keys, the choices (leads) of the couplet possess an equal distance from the left margin.

Example of an Indented Key on *Rhododendron*

1a. Flowers in shades of red
  2a. Flowers blood-red, leaves oblong-ovate, leathery and thick matty texture .... *R. sikkimense*
  2b. Flowers crimson-red, leaves broad, oval to elliptic oblong, shiny green above .... *R. fulgens*
1b. Flowers in shades of rose-pink
  3a. Calyx 3-5 mm long, leaf under surface covered with tufts of brown hair .... *R. wallichii*
  3b. Calyx obscure, 1-2 mm long, leaf under surface covered with continuous indumentum
    4a. Corolla in shades of deep rose-pink flushed externally with red-purple, young leaves aeruginose, leaf margins inrolled .... *R. aeruginosum*
    4b. Corolla pale lavender blue, mauve or rose-purple, *rarely* white, young leaves not aeruginose, leaf margins not inrolled .... *R. campanulatum*

The two choices of the couplet are usually labelled **1** and **1′** or **la** and **lb**. It is not necessary that the choices are numbered, but it helps. The user goes to the next indented couplet following the lead that was selected.

ii) Bracketed Keys:

Provides both choices side-by-side. The choices of the couplet must be numbered (or lettered). It is very helpful if the previous couplet is given. This key has exactly the same choices as the first example. The choices are separated, but it is easy to see the relationships. While this key might be more difficult to construct, it gives more information to the user.

Advantages of dichotomous keys:

a. Similar specimens are grouped together;

b. It is harder to get lost your place;

c. They are faster to use; and

d. It is easier to retrace your steps if you make a "wrong turn".

Disadvantages of dichotomous keys:

A key may be difficult to use at times because:

- ➢The key may not include all potential variations in the species;

Example of a Bracketed Key on *Rhododendron*

1a.	Flowers in shades of red	go to 2
1b.	Flowers in shades of rose-pink	go to 3
2a.	Flowers blood-red, leaves oblong-ovate, leathery and thick matty texture	*R. sikkimense*
2b.	Flowers crimson red, leaves broad, oval to elliptic oblong, shiny green above	*R. fulgens*
3a.	Calyx 3-5 mm long, leaf under surface covered with tufts of brown hair	*R. wallichii*
3b.	Calyx obscure, 1-2 mm long, leaf under surface covered with continuous indumentum	go to 4
4a.	Corolla in shades of deep rose-pink flushed externally with red-purple, young leaves aeruginose, leaf margins inrolled	*R. aeruginosum*
4b.	Corolla pale lavender blue, mauve or rose-purple, rarely white, young leaves not aeruginose, leaf margins not inrolled	*R. campanulatum*

- The key may rely on features not present in that season;
- The key may not include "**all**" species of interest;
- One may misinterpret a feature or make a mistake.

B. Poly clave keys:

- Poly clave keys are tools used to help identify unknown objects or species. The keys are generated using interactive computer programs. Polyclave keys use a process of elimination.
- The user is presented with a series of choices that describe features of the species they wish to identify. The user then checks off a list of character states present in the organism they wish to study.
- The program looks to match those character states with all the species they can possibly match. If a species does not have that character state it is eliminated from the list. The more character states listed the more species that are eliminated.
- This allows the rapid elimination of large numbers of species that the specimen cannot be. The process continues until only one species remains.

Advantages of Poly clave keys:

1) They are easy to use.

2) They allow multi-entry i.e. the user can start anywhere. This is a significant advantage because the user can rely on characters that are most easy to observe, rather than having to deal with characters that may not be present in the specimen or are poorly developed.

3) They are order-free i.e. the user can work in any direction with any character.

4) They are faster.

5) They are easily computerized. In fact, these keys are most commonly used in this form. Paper versions are typically large and unwieldy because each character needs to list all possible taxa.

Disadvantages: It is based on specimen and their availability. They have generally been written only for a limited number of taxonomic groups.

Polyclave Key: Example - Pollination Type

Pollination is the process of transferring pollen from one flower to another. Since plant can't move, they utilize vectors such as wind, water and animals to accomplish this process for them. Flowers are specialized by shape, color, odor, nectar reward in order to maximize the chance that a certain vector will accomplish pollination. These flower adaptations are collectively known as pollination syndromes.

Plants differ in the degree of their specialization for a particular pollination system. For example, many orchids are pollinated by only a single type of bee. Other flowers are not as specialized and may be pollinated by a variety of bees or perhaps beetles. In other cases, insects may visit flowers without actually transferring pollen. These factors make it difficult to determine with absolute certainty the pollination system by the polyclave key.

To illustrate how to use a polyclave key, let's determine the pollination system of a dandelion.

1. Select any one of the FLOWER CHARACTERS in the key.	*Let's choose FLOWER COLOR*
2. Choose the character state (description) that matches the flower you are observing	*Dandelions are **Yellow***
3. Write down the possible pollination systems for this feature	*BE,BU,BI*

(*BE-Bee pollination, BU-Butterfly pollination, BI-Bird pollination*)	
4. Select another feature	*NECTAR*
5. Choose the character state description that matches your flower (*WI-wind pollination, FM-fly pollination, BE-bee pollination, BA-bat pollination*)	*b. present...WI,FM,BE,BA*
6. Eliminate from the first character state selected the pollination systems not found on both lists. Continue this process until the pollination system is identified.	*BE,~~BU~~,~~BI~~* *Thus, dandelions are bee pollinated*

Abbreviation Code: **WI** Wind pollination (anemophily); **BT** Beetle pollination (cantharophily); **FM** Fly pollination (syrphid and bee flies; myophily); **FS** Fly pollination (carrion and dung flies; sapromyophily); **BE** Bee pollination (mellittophily); **BU** Butterfly pollination ; (psychophily); **MO** Moth pollination (phalaenophily & sphingophily); **BI** Bird pollination (ornithophily); **BA** Bat pollination (chiropterophily)

International code of Zoological Nomenclature (ICZN): Operative principles, interpretation and application of important rules: Formation of Scientific names of various Taxa

- One of the primary responsibilities of systematic biology is the development of our biological nomenclature and classifications.
- Nomenclature is not an end to systematics and taxonomy but is a necessity in organizing information about biodiversity.
- Nomenclature functions to provide labels (names) for all taxa at all levels in the hierarchy of life.
- Biological nomenclature derives from the binomial nomenclature that was originally codified in the works of Linnaeus, *Species Plantarum* (1753) and *Systema Naturae, 10th Edition* (1758). These publications are the decided starting points for the modern biological nomenclature in most groups of plants and animals.
- Taxa at the level of species are named with binomials, consisting of generic and specific names that together equal the species name.
- Taxa above the level of species are Supraspecific Taxa and are Uninominals.

o Taxa below the level of species are Subspecies or Trinominals.

History of Nomenclature Codes:

1758 Linnaeus' 10th Edition of *Systema Naturae*

1840 Strickland Code of British Association for the Advancement of Science

1867 Set of "laws" at Paris International Botanical Congress

1881 French Code developed

1887 U. S. Code developed

1889 International Zoological Congress adopted Blanchard Code

1894 German Code developed

1901 Regles International Nomenclature of Zoology adopted by 5th Congress, published under the 6th Congress in 1905

1904 International Commission on Zoological Nomenclature (ICZN) formed

1913 Plenary powers granted to ICZN

1952 International Code of Botanical Nomenclature

1953 Publication of Copenhagen Decisions and the Follett Summary (1955)

1958 Rewritten as international code and updated since that time

1976 International Code of Nomenclature of Bacteria
1985 Publication of International Code of Zoological Nomenclature
1994 Most recent Code of Botanical Nomenclature
1999 Most recent Code of Zoological Nomenclature

Parts of International Code of Zoological Nomenclature:

The International Code of Zoological Nomenclature contains three main parts:
(i) The Code proper, (ii) The Appendices and (iii) The Official Glossary

- The code proper includes a preamble followed by 90 articles (grouped in 18 Chapters) which cover mandatory rules without any explanation.
- There are three Appendices, of which the first two cover the status of recommendations and the third part of the Appendices is the constitution of the commission.
- The glossary contains the terms used in the codes with detailed definition.
- The English and French texts of the Code are published on behalf of the Commission by the International Trust for Zoological Nomenclature.

Rules of Zoological Nomenclature:

At present the naming of the animal is governed by the International Code of Zoological Nomenclature. There are many rules (Articles) concerning the Zoological Nomenclature.

Some important ones are cited below:

1. Zoological nomenclature is independent of other system of nomenclature. The scientific name of animals and plants must be different, and the generic name of a plant and an animal may be same, but this system is to be avoided. e.g., the generic name of banyan or fig tree is *Ficus* and the fig shell (a gastropod shell) is *Ficus*. The scientific name of fig tree is *Ficus carica* or *F. indica*, *F. religiosa, F. bengalensis* etc., but the scientific name of the fig shell is *Ficus ficus* or *Ficus gracilis*, etc.

2. The scientific name of a species is to be binomial (Art. 5.1) and a subspecies to be trinomial (Art. 5.2).

e.g., the scientific name of Indian bull frog is *Rana tigerina*. It is binomial. The scientific name of Indian lion is *Panthera leo persica*. It is trinomial. Such a system of naming by three Latin or Latinized words is known as trinomial nomenclature.

3. The first part of a scientific name is generic (L. Genus = race) and is a single word and the first alphabet or letter must be written in Capital letter. The genus must be a noun in the nominative singular. The generic part assigns a Latin noun, a Latinized Greek or a Latinized vernacular word.

4. The second part of a name is species (L. species = particular kind) name and may be a single word or a group of words. The first alphabet or letter of the species name must be written in small letter. The species name must be adjective form in nominative singular agreeing in gender with genus name which is in noun form; e.g.:

The specific name indicates distinctness while generic part shows relationship.

5. If the species names are framed after any person's name, the endings of the species are *i, ii* and *ae*, or if the species name are framed after

Ending in species name	**Ending in genus name**	**Full name of the species**
Masculine ending (–i)	(–i/–us/–es)	Common mongoose (*Herpestes edwardsi*) River lapwing (*Vanellus duvaucelli*)
Feminine ending (–a/–e)	(–a/–e)	Golden cuttle fish (*Sepia esculenta*) Humpnosed viper (*Hypnale hypnale*)
Neuter ending (–um/–us, etc.)	(–um/–us, etc.)	Tusk shell (*Dentalium elephantinum*) Common crane (*Grus grus*) Lesser black-backed gull (*Larus fuscus*)

geographical place, the endings of the species are '*ensis*', '*iensis*', e.g.:

6. First part of a compound species-group name is a Latin letter and denotes a character of the taxon, connected to the remaining part of the name by a hyphen (-) e.g., Sole (a kind of flat fish)—*Aseraggodes sinus-arabici* L. Sinus = recess

China-rose (a kind of coloured rose) — *Hibiscus*

Species name after person's name	**Hooded cuttle fish** — *Sepia prashadi* (Prasad + i) **Tree frog** — *Rhacophorus jerdonii* (Jerdon + ii) **Antarctic flying squid** — *Todarodes filippovae* (Filippov + ae)
Species name after place	**Common Indian monitor** — *Varanus bengalensis* (Bengal + ensis) **Cookiecutter shark** — *Isistius brasiliensis* (Brasil + iensis) **Butterfly fish** — *Chaetodon madagascariensis* (Madagascar + iensis)

rosa-sinensis L. rosa = rose

7. If a subgenus taxon is used, it is included within parenthesis in between genus and species part and is not included in binomial and trinominal nomenclature, e.g.:

Name	Genus	Subgenus	Species	Subspecies
Fan shell (Bivalvia)	*Atrina*	*(Servatrina)*	*pectinata*	*pectinata*
Dussumieri's half beak (Osteichthyes)	*Hemirhampus*	*(Reporhampus)*	*dussumieri*	

8. The person who first publishes the scientific name of an animal, is the original author of a name, may be written after the species name along with the year of publication. The author's name may be in its abbreviated form.

Lion- *Felis leo* Linnaeus, 1758; Lion- *Felis leo* Linn., 1758; *Felis leo* L., 1758

9. Comma is only used between author's name and the year of publication (Art. 22. A. 2.1), e.g., the scientific name of Common octopus is *Octopus vulgaris* Cuvier, 1797. No punctuation marks are considered one to other ends of the name, e.g., "*Octopus vulgaris* Cuvier, 1797" (Not considered). No diacritic mark, apostrophe (i') and hypen (-) are used in names. In German word the umlaut sign is removed from a vowel and the letter 'e' is inserted after the vowel, e.g., Mülleri becomes Muelleri.

10. If the original generic name given by the first author who also reported the species name, transfers the species part from one genus to the

other, the name of the original author is put within parenthesis, e.g.,

Tiger:

Felis tigris Linnaeus, 1758. At first almost all the members of the cat family were placed under the genus-*Felis*.

Later the genus *Felis* was divided into two genera, the genus of the larger cats (tiger, lion, leopard, etc.) is *Panthera* and smaller cats such as jungle cat, fishing cat, golden cat, etc. are placed under the genus *Felis*, e.g.:

Lion- *Felis leo* Linnaeus, 1758 – Lion - *Panthera leo* (Linnaeus, 1758)

Jungle cat- *Felis chaus*

11. The names are not acceptable before the publication of Linnaean treatise, *Systema Naturae* (10th edition) which was published on 1st January, 1758 except the Nomenclature of spiders which starts in 1757. The book *Aranei suecici* was published by C. Clerck in 1757.

12. The scientific names must be either in Latin or Latinized or so constructed that they can be treated as a Latin word.

13. The scientific names must be italicized in printed form, or underlined in hand written or in typed forms, e.g.

Indian leopard- *Panthera pardus fusca* (Meyer)

14. All taxa from subgenera level and above must be uninominal (Art. 4.1, 4.2) and are plural nouns for names above genus, and singular nouns for genus and subgenus. Taxon 'species' may be used as singular or plural.

15. In case of animals some rules and practices are applied on the basis of zoological codes (Art. 29.2) for the formation of supra generic taxa from superfamily to tribe, e.g.

16. A family name should be based on the basis of type-genus, e.g., Chitonidae—Chiton (type genus)

Taxon level	**Endings of the name**	**Examples**
Superfamily	—oidea (for vertebrates) or —acea (for invertebrates)	Hominoidea Genus *Homo* (Latin) = man Genitive *Hominis* Root *Homin*—of *Homo*
Family	—idae	Hominidae [Homin + idae]
Subfamily	—inae	Homininae [Homin + inae]
Tribe	—ini	
Subtribe	—ina	

+ idae = Chitonidae.

17. Two species under a same genus should not have the same name.

18. Nomenclature of a hybrid/hybrids cannot be considered because the hybrids are normally individuals but not population. Thus such names have no status in nomenclature. Hybrids are typically sterile and become synaptic failure during meiosis. They are prevented from back crossing with either parental species.

19. A name published without satisfying the conditions of availability (nomen nudum = naked name) has no standing in zoological nomenclature and is best never recorded, even in synonymy.

20. A scientific valid name which is not used about 50 years in literature, then as per zoological code's provision the unused senior valid scientific name is treated as obliterated name and junior name which is used continuously in literature (at least by 10 authors in 25 publications) becomes the accepted official name.

Remark:
The disadvantage of the binominal system is its instability and the name of a species changes every time and is transferred to a different genus.

21. As per the zoological code's provision, the species and subspecies parts of a name may be same spelling and even the second or the third component of the name repeats the generic name (tautonomy), e.g.: Scandinavian red fox- *Vulpes vulpes vulpes*

22. Synonyms are the different names for a same animal or a taxon (species or genus). If the several scientific names are given to a single animal by different scientists, the senior-most name is selected by law of priority. The senior-most or earliest name is called senior synonym (Art. 10.6) and is considered as valid species and the rest of the names are called junior synonyms and are treated as invalid species.

The leopard cat was named *Felis bengalensis* by Kerr and the same animal was named by Gray, *Felis chinensis*. Again this animal was named as *Prionailurus bengalensis* by Kerr. So the first name is senior synonym and valid and the rest names are junior synonyms and are invalid.

The whale shark was named *Rhiniodon typus* by Smith in 1828 and the same was named *Rhinodon typicus* by Muller and Henle in 1839, *Micristodus punctatus* by Gill in 1865 and *Rhinodon pentalineatus* by Kishinouye in 1891. Here the first name is considered as senior synonym (*Rhiniodon typus*) and valid, the rest are junior synonyms and are invalid.

23. Homonyms mean when identical names are given to two or more different taxa. According to the zoological code (Art. 52.2) when two or more homonyms are found, the senior most (oldest) homonym (Art. 52.2) is used and the junior-most homonyms are replaced with new names, e.g., Cuvier proposed the genus *Echidna* in 1797 for the spiny anteater.

Forster already proposed the genu *Echidna* in 1777 for morey eels. According to Law of Priority, Forsters genus claimed senior homonym and Cuvier's genus considered as junior homonym. *Illiger* replaced the Cuvier's name as *Tachyglossus* for spiny anteater in 1811.

Taxonomic Categories?

Taxonomic Hierarchy Categories were also introduced by Linnaeus. They are also known as

Linnaean hierarchy. It is defined as sequence of categories in a decreasing or increasing order from kingdom to species and vice versa. Kingdom is the highest rank followed by division, class, order, family, genus and species. Species is the lowest rank in the Hierarchy. The hierarchy has two categories which are obligate and intermediate. Obligate means they are followed strictly and range from kingdom to species as said above. Intermediate are not followed strictly and they are added in obligate list such as subdivision, super family, super class, suborder, subspecies etc.

1. Kingdom: The top most taxonomic category. Example all animals are included in Kingdom Animalia. The unit in classification that denotes grouping of organism based on features which are observable is known as Taxon.

The different methods used to identify and classify organisms are referred to Taxonomic aids. Identification of organisms is a tedious process. Keys are used for identification referred as Taxonomic key. It includes a long table of statements with alternative features to identify organisms. The features which are related to organism are chosen.

2. Phylum: It is a term used for animals while its synonym division is used for plants. It is a collection of similar classes. Phylum chordata of animals has class mammalia along with birds, reptiles and amphibians.

3. Class: One or more than one order makes a class. Class mammalia includes all mammals which are bats, rodents, kangaroos, whales, great apes and man.

4. Order: One or more than one similar families constitute order. Family felidae are included in the order Carnivora. Order puts them in a general group of what they are, like the group turtle, which including all turtles.

5. Family: In biological classification, family **(Latin: familia, plural familiae)** is one of the eight major taxonomic ranks; it is classified between order and genus. A family may be divided into subfamilies, which are intermediate ranks above the rank of genus. In vernacular usage, a family may be named after one of its common members. It can be separated from genera by reproductive and vegetative features.

6. Genus: The classification of kingdom is very general and includes the animal kingdom or plant kingdom. In contrast, the division of genus is more specific as the grouping before species and after family. It is defined as group of similar species. But it is not mandatory to have many species.

Some genera have only one species known as *Monotypic*. If there are more than one species it is known as *Polytypic*. For example lion, tiger are quite similar species placed under the genus Panthera.

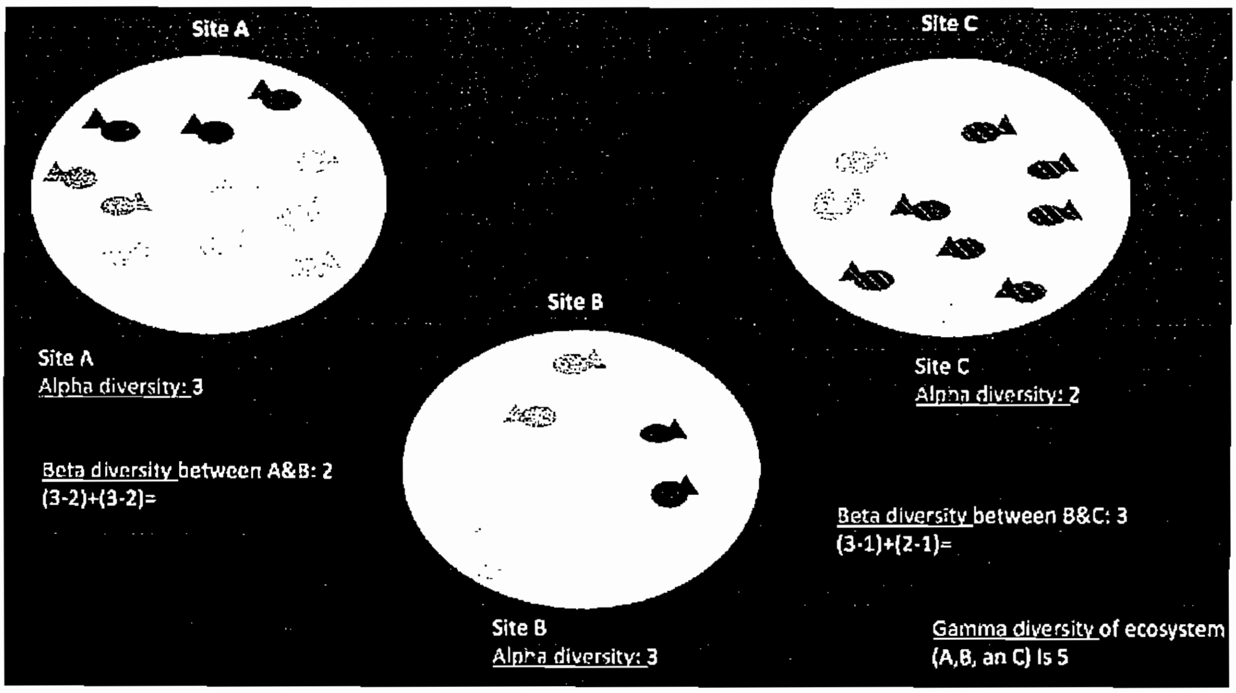
7. Species: The biological species concept defines a species as members of populations that actually or potentially interbreed in nature, not according to similarity of appearance. Although appearance is helpful in identifying species, it does not define species.

Unit IV

Evaluation of biodiversity indices. Evaluation of Shannon Weiner Index. Evaluation of Dominance Index. Similarity and Dissimilarity Index.

The variety of life on Earth is commonly referred as biological diversity or biodiversity. Biodiversity is one of the primary interests of ecologists, but quantifying the species diversity of ecological communities is complicated.

The biodiversity indices aim to describe general properties of communities that allow us to compare different regions, taxa, and trophic levels. They are of fundamental importance for environmental monitoring and conservation, although there is no consensus about which indices are more appropriate and informative.



The spatial component of biodiversity can be termed as alpha, beta, and gamma diversity. Imagine that you have a landscape containing of a number of separate sites and habitats. **Alpha diversity** is just the diversity of each site/habitat (local species pool). **Beta diversity** represents the differences in species composition among sites/habitats. **Gamma diversity** is the diversity of the entire landscape (regional species pool).

Diversity mainly includes two different aspects: species richness and evenness. Species richness, or the number of species, is the simplest measure of diversity and does not consider differences in species relative abundance. That is, each species is not likely to have the same number of individuals. One species may be represented by 1000 birds, another by 200 and a third only a single bird species.

Species evenness is the similarity in species relative abundance in a community. The majority of studies on biodiversity have used species richness to represent diversity on account of its apparent simplicity compared to species evenness.

Diversity indices are mathematical functions that combine richness and evenness in a single measure. The most commonly used diversity indices are: Shannon's diversity and Simpson's diversity indices.

Shannon Diversity Index

The Shannon index increases as both the richness and the evenness of the community increase. The fact that the index incorporates both components of biodiversity can be seen as both a strength and a weakness. It is a strength because it provides a simple, synthetic summary, but it is a weakness because it makes it difficult to compare communities that differ greatly in richness. Typical values are generally between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4.

$$H' = -\Sigma\, p_i \ln p_i$$

Where,

H' = Shannon index of diversity

p_i = the proportion of important value of the i^{th} species ($p_i = n_i / N$, n_i is the important value index of i^{th} species and N is the important value index of all the species).

To calculate the index:

1. Divide the number of individuals of species #1 you found in your sample by the total number of individuals of all species. This is p_i
2. Multiply the fraction by its natural log (p_i * ln p_i)
3. Repeat this for all of the different species that you have.
4. Sum all the - (p_i * ln p_i) products to get the value of H'

Example 1:

S. No.	**Name of species**	**N**	***pi***	***lnpi***	***pi lnpi***
1	Pigeon	10	0.05	-2.912	-0.158279927
2	Robin	4	0.02	-3.829	-0.083231335
3	Myna	9	0.05	-3.018	-0.147605438
4	Crow	7	0.04	-3.269	-0.124365105
5	House sparrow	11	0.06	-2.817	-0.168410029
6	Grasshopper	15	0.08	-2.507	-0.20436567
7	Butterfly	11	0.06	-2.817	-0.168410029

8	Snake	1	0.01	-5.215	-0.028342042
9	Frog	12	0.07	-2.730	-0.178045377
10	Monkey	10	0.05	-2.912	-0.158279927
11	Owl	4	0.02	-3.829	-0.083231335
12	Chital	18	0.10	-2.325	-0.227403
13	Drango	21	0.11	-2.170	-0.247710216
14	Blue Jay	15	0.08	-2.507	-0.20436567
15	Egret	17	0.09	-2.382	-0.22005044
16	Heron	19	0.10	-2.270	-0.234453472
	Total	184	1	-47.5	**-2.636549012**

H = 2.636

Example 2:

Birds	**N_i**	**P_i**	**$ln\ P_i$**	**$-(P_i * ln\ P_i)$**
Pigeon	96	.96	-.041	.039
Robin	1	.01	-4.61	.046
Starling	1	.01	-4.61	.046

Crow	1	.01	-4.61	.046
House sparrow	1	.01	-4.61	.046

H = 0.223

High values of H' would be representative of more diverse communities. A community with only one species would have an H' value of 0 because p_i would equal 1 and be multiplied by ln p_i which would equal zero. If the species are evenly distributed then the H' value would be high. So the H' value allows us to know not only the number of species but how the abundance of the species is distributed among all the species in the community.

Evaluation of Dominance Index (Simpson's index):

Dominance is one of the most important concepts in the study of animal social behaviour. Dominance hierarchies in groups arise from dyadic relationships between dominant and subordinate individuals present in a social group. In concrete way, dominance is an important indicator of species composition in a habitat. The dominance of a species refers to its relative importance in its habitat, which determines the degree of influence of the species on the ecosystem. Ecologists have spent much effort and imagination to establish and quantify interrelationships among these components, and to identify the underlying biological or physical processes that influence them, e.g., extinction, immigration, colonization, niche segregation, competition, predation, environmental control, disturbances, and historical dynamics.

The Simpson index is a dominance index because it gives more weight to common or dominant species. In this case, a few rare species with only a few representatives will not affect the diversity.

Simpson's index $D = \Sigma (p_i)^2$

Where,

D = Simpson index of dominance

p_i = the proportion of important value of the i^{th} species ($p_i = n_i / N$, n_i is the important value index of i^{th} species and N is the important value index of all the species).

As D increases, diversity decreases and Simpson's index was therefore usually expressed as $1 - D$ or $1/D$.

Example 1 (site 1)

Order	n	Pi	pi^2	ln pi	pi ln pi
Orthoptera (grasshopper)	6	0.222222	0.049383	- 1.50408	- 0.33424
Orthoptera (grasshopper)	5	0.185185	0.034294	-1.6864	-0.3123
Lepidoptera (butterfly)	1	0.037037	0.001372	3.29584	0.12207
Lepidoptera (butterfly)	3	0.111111	0.012346	- 2.19722	- 0.24414
Coleoptera (beetle)	12	0.444444	0.197531	- 0.81093	- 0.36041
	27	1	**0.294925 =** $\Sigma(p_i)^2 = D$	- 9.49447	- 1.37315
		1/ $\Sigma(p_i)^2$ = D	**3.390698**		

Number of species = 5

Total number of individuals = 27

$\Sigma (p_i)^2 = 0.294$

$\Sigma p_i \ln p_i = -1.373$

H' = -(-0.334 + -0.312 + -0.122 + -0.244 + -0.360) = **1.373**

D = 1/(0.049 + 0.034 + 0.001 + 0.012 + 0.197) = 1/0.294 = **3.390**

Example 2 (site 2)

Order	(n)	Pi	pi^2	ln pi	pi ln pi
Orthoptera (grasshopper)	99	0.99	0.9801	- 0.01005	- 0.00995

Orthoptera (grasshopper)	1	0.01	0.0001	-4.60517	-0.04605
	100	1	0.9802 = $\Sigma(p_i)^2$ = D	-4.61522	-0.056
		1-$\Sigma(p_i)^2$ = D	0.020		

Sorensen's Index:

- This measure is very similar to the Jaccard measure, and was first used by Czekanowski in 1913 and discovered anew by Sorensen (1948).
- Give greater "weight" to species common to the quadrats than to those found in only one quadrat.
- Indices of similarity and dissimilarity were calculated by using formulae as per Misra (1989) and Sorensen (1948) as follows:

Index of similarity (S) = 2C/A+B

Where,

A = Number of species in the community A

B = Number of species in the community B

C = Number of common species in both the communities.

Index of dissimilarity = 1-S

Example 1:

There are 20 species found in community 1 and 25 in community 2. Between them, they have 5 species in common. The calculation would be:

Sorenson's Coefficient (CC) = $\frac{2*5}{20+25}$ = 10/45 = 0.222

According to Sorenson's coefficient, these communities do not have much overlap or similarity.

Example 2:

There are 15 species found in community 1 and 25 in community 2. Between them, they have 12 species in common. The calculation would be:

Sorenson's Coefficient (CC) = $\frac{2*12}{15+25}$ = 24/40 = 0.6

According to Sorenson's coefficient, these communities have quite a bit of overlap or similarity.

Biosystematics.
(Importance and Applications)

Biosystematics is the study of biological diversity and its origin. The discipline includes collection, naming, classification and describing of organisms as well as a reconstruction of their evolutionary history. Systematic biology has developed strongly during the last decades, partly due to improved molecular techniques and more powerful computers. This has increased our knowledge of how life on earth has developed and how organisms are related to one another.

Many scientific disciplines depend on the results from systematic biology. Analyses of evolutionary processes rely on well-founded hypotheses of evolutionary relationships. A reliable identification of species is a prerequisite for scientific work involving organisms of any kind, especially in applied science, for example agriculture, horticulture and many others.

Systematic biology stands out among biological sciences is being dependent on research on historical collections and publications. Scientists and historians generally consider the works of Carl Linnaeus as cornerstones in the main foundation of systematic biology.

Importance and Major Applications

1. In Biodiversity and Conservation

Approximately 1 million species of animals and 0.5 million species of plants have so far been identified and described by taxonomists during the last 230 years. This forms only 10% or less than 10% of the world's organisms. It may take several thousand years to identify and describe the remaining species if the number of expert taxonomists is not increased from the present state. It is believed that several hundreds of species may become extinct before we discover them. In order to know which species are endangered or threatened we must know what they are and what we have to conserve.

2. In Research field and Studies

Before starting any kind of studies, one needs to know the correct scientific name of the organisms on which one is going to study. This is important because the correct scientific name of the organism is a functional label using which various pieces of information concerning that organism, including all the past work done on it, can be retrieved and stored ensuring easy reference. To give an example how a research effort could land in trouble if the organisms involved are not identified by expert taxonomists, an interesting real but sad story which happened in a South Indian University is sighted. A professor (a non-taxonomist) gave a research problem on the reproductive physiology of two species (?) of crabs to two different students (one student had to work with one species and the other on another species). Both these students worked on their respective species of crabs for two years and then the guide (research supervisor) got these specimens identified by a specialist who found that the two 'species' of crabs represented one species as the differences involved were only variations. This had resulted in utter confusion and finally one student had to change the topic of his research after wasting' two years. This clearly shows how important it is to get one's specimens identified by an expert taxonomist before one starts working on it.

3. In the field of Medicine

Taxonomic identification of the organism, which causes or transmits disease, is absolutely essential for effective treatment. The work of Nathen Charles Rothschild the renowned taxonomist on flea species in collaboration with L. Fabian Hist, a health officer in Sri Lanka resulted in the discovery that the prevalent rat-fleas of India and other regions of the Orient did not constitute a single species and the geographic distribution of different species of rat-fleas in India was one of the most important factor governing the spread of plague. Taxonomists contributed greatly to the successful control of malaria in Europe by providing correct identification of anopheles species of mosquitoes connected with disease causing parasites. There are several species and infraspecific categories of plants that are used in Ayurvedic medicine. The traditional practitioners used some crude or native methods to identify each variety of plants. Scientific taxonomic identification of these plants has contributed greatly in recent times to the preparation of Ayurvedic medicine in much more effective ways.

4. In the field of Agriculture and Pest management.

Taxonomy plays a major role in the management of crop pests by biological means. The correct identification of both the pest and its natural enemies is of utmost importance when the natural enemies are imported or transferred from one region to another in order' to bring about biological control of the pests. Taxonomists through their research and assistance can help biological control workers by :

a. Providing correct identification of pest species and information on its probable home.

b. Directing and conducting surveys for natural enemies existing in the original home of the pest.

c. Making an inventory of natural enemies and alternate hosts of the natural enemies in the country of introduction.

d. Providing catalogues, revisions, handbooks, host-parasite lists, identification keys etc.

e. Help the biological control workers to find pertinent information hidden under obsolete species name and

f. Help to differentiate between introduced and indigenous natural enemies in order to properly document the effect of biocontrol programmes.

5. In pest identification

Correct identification of the target pest is the most important step to be taken before initiating any biological control programme. For this a taxonomist's help is absolutely essential. Once the species is correctly identified, its original home can be ascertained and all available information on its biology, natural enemies, distribution etc can be retrieved and stored. A wrong identification of the pest can lead (this usually happens when the identification is not made by a bonafide specialist) to unnecessary wastage of time, energy and money in searching and finding the natural enemies of the pest in question.

6. In Quarantine

In order to prevent accidental or otherwise introduction of plants and animals to a country from another country, governments have established quarantine laboratories in every nation. These quarantine agencies inspect every plant or animal brought to the respective countries. With the help of taxonomists the quarantine agencies determine whether the imported plant or animal is harmful or not and based on their advise, prevent the entry of harmful plants and animals.

7. In National Defense

In these days of germ warfare, it is essential to identify the organisms introduced into a country by the enemies. For each soldier it is necessary to have some basic knowledge of taxonomy to recognize the local fauna and flora with which he has to work so that contact with disease spreading animals or plants can be avoided. Making available the valuable contributions by taxonomists over the years can make the identification of dangerous organisms in the war areas easy.

8. In Fisheries

In order to find out the edible varieties of aquatic organisms,' taxonomist's help can be sought for better prospects. Taxonomic knowledge of organisms that form food for fishes can help the fishermen to locate the localities where these organisms are abundant. The distribution of each aquatic organism can be found out from the relevant taxonomic publications or with sharing the unpublished information the specialist can provide.

9. In Parasitology and Veterinary Science

As in the case of identification of parasites of man, a taxonomist's contribution will be of great help in veterinary science also. A thorough taxonomic revision of these parasitic organisms will be of much use for practitioners of veterinary and as medical sciences. Thus taxonomy, parasitology, veterinary and medical sciences are all interconnected and interdisciplinary and one cannot exist without the other. Herein lays the importance of taxonomy to other branches of science.

Although in the past much Systematic research was based upon morphological and anatomical similarities, the ability of biochemists to describe the structure of certain proteins and to compare the similarity of genetically important molecules as DNA (deoxyribonucleic acid) in different organisms has provided another approach to the understanding of the relationships of various species to one another. The field of Systematic is so broad that no one person can possibly hope to make contributions to all of the above areas. Instead, Systematists choose a particular group of organisms of special interest and the best method to use in studying it. Only with numerous biologists working together can we hope to map the diversity and dynamics of nature.

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Organic Evolution

Chapter · January 2013

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Introduction

Since antiquity humans have been observing a great variety of living organisms on the earth .

Figure : Representatives of various domains (a) Bacteria (b) Archea –Thermophiles (c) Eukarya Plantae and Animalia (d)

Source: http://cnx.org/content/m44388/latest/Figure_01_02_17abcd.png

The very basic question that comes in our minds is – Why is there so much of biodiversity on the earth? And further, who has created all of this? Different people have attempted to answer such questions related to biodiversity. One group of people (religious group) searched the answers of these questions in realms of various religious texts and proclaimed all biodiversity to be created by a supernatural power, the God. Apart from this, there is another group of people (scientific group), which on the basis of various systematic investigations has suggested that present day organisms are the outcome of a long and continuous series of changes called **organic evolution**. The vast biodiversity that we see now on our planet, is the result of same evolutionary process.

Organic evolution

From physico-chemical state point of view, life is an **open system**, which maintains its ordered structure and performs its functions by obtaining the building blocks and energy from its surroundings. For that, it requires an ordered and sequential functioning of its various components, each having a definite structure. One of the characteristic features of a living system is **reproduction** that is possible only when it has a self-building mechanism and a system of information storage and transfer (genetic material). The living system functions properly, only when it is in harmony with its environment. However, the environment always has a tendency to change. Therefore, in order to maintain harmony a living system must change with its changing environment by bringing suitable changes in its various structural components. The suitable changes in the structure of a living system can only be incorporated permanently through the changes in its genetic material. All the living organisms show this ability to change and adapt according to changed conditions. This inbuilt capability of living organisms to adjust and change according to changing environmental conditions is known as organic evolution or simply evolution, which ultimately transforms them into new living forms over a long period. The evolution is a continuous, gradual and an orderly process that always remains in action, and is responsible for fixing the genetic changes in the hereditary material of a **population**.

Theories of organic evolution

In order to explain evolution, a number of theories have been proposed. Some of the important theories are following.

1. **Theory of special creation or divine origin:** This is the most primitive theory and refutes the concept of evolution. According to this theory all living forms present on the earth were specially created once and for all by a supernatural power. Since all these organisms are of divine origin, they are permanent and non-changeable entities that exist in the same form in which they were created initially. Many of the religious faiths are based on this concept, for instance, Christianity believes that present world was created about 4000 B.C. and to be more precise, on 23rd of

October, 4004 B.C. at 9:00 AM on Sunday as pronounced by Archbishop James Ussher in 17th century. Similarly, Hindu mythology says that Brahama, the God of creation, has created all the living organisms.

2. **Idealistic Concept:** Plato (428-348 B.C.) suggested that all observable things are imperfect representations of an ideal unseen world. According to this concept, initially there was a world of ideals (most perfect living forms) and any change in these ideals resulted into disharmonies (less perfect living forms). This concept was based on generalization of things and any variation to it was considered as an illusion.

3. **Scale of nature concept:** Aristotle (384-322 B.C.) extended the philosophy of Plato and arranged different living forms in the progressive fashion from most imperfect (simple) to most perfect (complex).

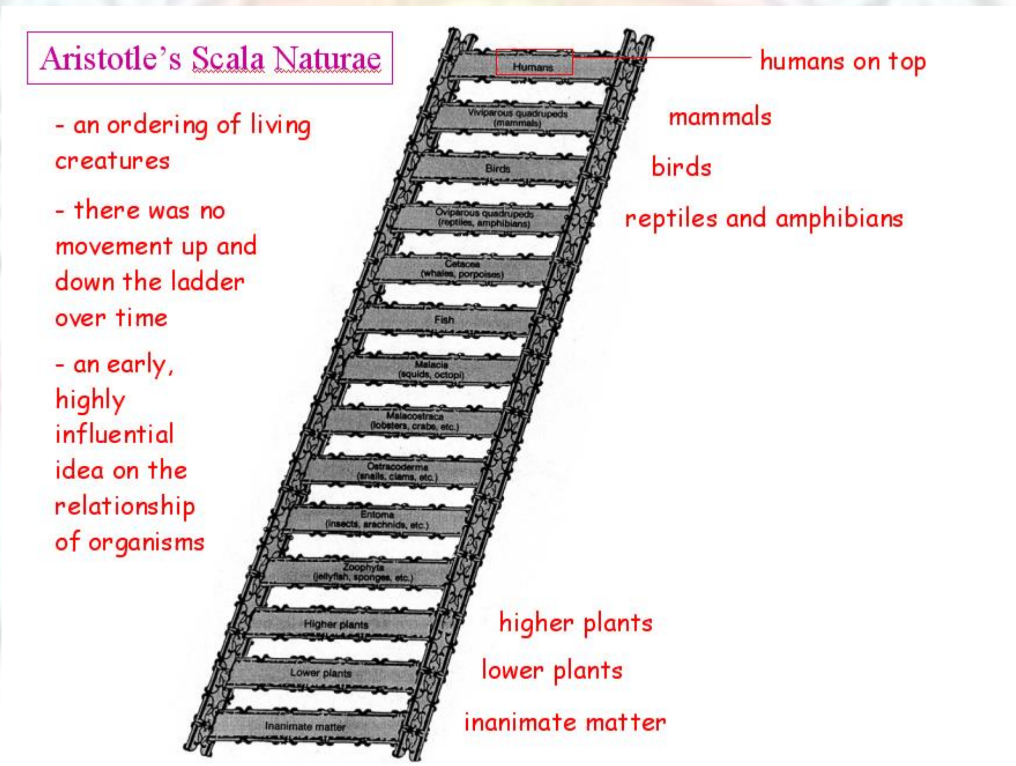

Figure: Scale of nature, a progressive arrangement of organisms (simple to complex).
Source: http://biology200.gsu.edu/houghton/2107%20%2713/Figures/General/Aristotle.jpg

4. **Catastrophism:** George Cuvier (1769-1832), in order to explain sharp discontinuities observed in **fossils**, proposed that fossils, which appear in different strata of sedimentary rocks, are the remnants of life destroyed by various catastrophes. Each catastrophe is followed by recreation of a new life by God.

5. **Gradualism:** James Hutton and Charles Lyell (1795) proposed that unlike the Biblical view, the earth is older than few thousand years. Since its inception, the earth has undergone numerous geological and climate changes that occurred slowly but continuously over geological time scale. These changes not only changed the earth but also the life and therefore, life has evolved gradually along with the evolution of earth. This theory is widely accepted and has two schools – Lamarckism and Darwinism, on the basis of mechanism of evolution as given below.

6. **Theory of inheritance of acquired characters:** Jean Baptiste de Lamarck (1809) in his book "Philosophie Zoologique" proposed this theory and that is why it is also called Lamarckism.

Figure : Jean-Baptiste de Monet Chevalier de Lamarck

Source: http://commons.wikimedia.org/wiki/File:Jean-Baptiste_de_Lamarck.jpg

According to this, living organisms evolved gradually through evolution involving two mechanisms.

(i) **Principle of use and disuse:** In response to the environment, different organisms in their lifetimes use some organs frequently and continuously in comparison to others. The frequently and continuously used organs consequently become more developed whereas unused or little used organs become weak and finally disappear. In other words, environment induces changes in living organisms.

(ii) **Inheritance of acquired characters:** Offspring inherit the characters acquired by their parents in their lifetimes provided that acquired modifications are common to both of the parents or at least to the maternal parent.Individuals in a population adapt themselves in response to changing environment and transmit these adaptations to their progeny. With passage of time, accumulation of variations takes place in organisms and this lead to the transformation of a species into a new species. In support of this theory, Lamarck took help of fossil records and said that evolution of present day longneck giraffe took place from short-neck forms. Because, reduced ground vegetation forced the ancestors to stretch their short necks in efforts to feed on the leaves of tall trees. Similarly, legless snakes were evolved from legged ancestors so that they could move or crawl through thick vegetation. However, this theory has been criticized for supporting the transfer of environment mediated somatic changes to progeny from parents. Weismann amputated the tail of mice continuously for 22 generations and even after the offspring had a tail as long as in the original parents. He established that changes occurring in the germplasm are heritable whereas those occurring in somatic cells are non-heritable. Since in response to change in environment, somatic cells are the ones that acquire new changes thus, remain non-inheritable.

7. **Theory of natural selection:** In 1831, Charles Darwin a fresh pass out from Cambridge University on the recommendation of his Professor of Botany (Reverend John Henslow), got an unpaid post of naturalist aboard HMS Beagle, a ship commissioned by the British Admiralty for a surveying expedition around poorly known stretches of the South American Coastline. This ship sailed in different parts of globe for five years and during this period Darwin studied the geography, flora and fauna of these regions. The observations made and the specimens collected by him especially from Argentine pampas and Galapagos Islands, paved the way for Darwin to understand the process of evolution. On his return to England in 1836, he kept working on the concept of evolution for 22 years and during this period he came across a book “An essay on the principles of population” written by Thomas Malthus (1798) in which, it was postulated that reproductive capacity of mankind exceeds the food supply available to an expanding human population. As a result, humans compete among themselves for the necessities of life leading to misery, war, famine and conscious control of reproduction these in turn regulate the population. Inspired by his views, Darwin applied the same in development of the concept of evolution. Meanwhile, another British naturalist, Alfred Russel Wallace, also independently conceived the idea of evolution similar to Darwin’s idea on the basis of his explorations and collections in South America and the East Indies (South East Asia). In June of 1858, Wallace sent Darwin an essay entitled “On the tendencies of varieties to depart indefinitely from the original type”. On receiving this essay, Darwin found the views expressed by Wallace remarkably, similar to his own. Rather than competing with each other to be the first to publish, Darwin and Wallace agreed to read their papers jointly before Linnaean Society of London on July 1, 1858.

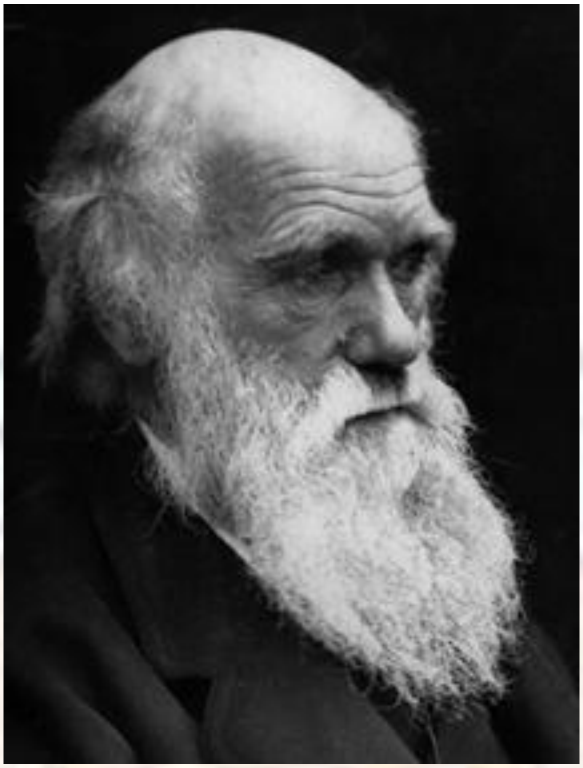

Figure : Charles Darwin

Source: http://commons.wikimedia.org/wiki/File%3ADarwin_Profile.JPG

Figure : Alfred Russel Wallace

Source: http://commons.wikimedia.org/wiki/File:Alfred_Russel_Wallace.jpg

Subsequently, in 1859, Darwin published his famous book "On the origin of species by means of natural selection or the preservation of favoured races in the struggle for life" in which, he elaborated the theory of natural selection. According to this theory, new species originate from their ancestral ones by gradual accumulation of adaptations over a very long period of time and adaptations are acquired because of natural selection. This theory is mainly based on three important observations and two conclusions derived logically from these, which are following.

1. **Tendency of overproduction:** All living organisms have high rate of reproduction and if, all the newborn of one particular species happen to survive and reproduce there would hardly be any space left for others to live. Thus, this will lead to overpopulation as population increases in exponential manner (1,2,4,8,16,32----). For example, a female Salmon fish produces around 28 million eggs at one spawning; a tropical orchid plant may form over 1 million seeds in a year. Similarly, considering the elephant, which is one of the slowest breeders having a breeding life from 30 to 90 years. It bears on an average 6 young ones in a life span of 100 years. If all these young ones survive and breed at the same rate then about 19 million elephants will be produced within a period of 750 years.
2. **Stability of population size:** Second important observation made by Darwin was that though the reproduction rate of a species remains high, the actual size of population of that species remains relatively constant over long period of time under a fairly stable environment.
3. **Variations:** Darwin's third observation was that individuals in a population are not all alike but differ from one another minutely with respect to different characters. All these differences constitute variations or polymorphism in a population.

Above observations and their interpretation led Darwin made two deductions.

1. **Struggle for existence:** On the basis of first and second observation, Darwin concluded that not all individuals that were born in any generation could survive. He explained this in terms of struggle for existence, which means that although organisms tend to overproduce but, in nature the resources required by living organisms for their survival, especially food and space, are limited. Because of this limitation of resources only limited individuals will be able to utilize those available resources and rest will be deprived and therefore, will ultimately be eliminated. In order to grab available resources, the individuals in a population compete amongst themselves (intra specific competition), with individuals of other species (inter specific competition) and with adverse environment as well. These different types of

competitions lead to a struggle for survival or existence and keep the number of individuals of a population in a particular range that can be sustained by the available resources.

2. **Survival of fittest:** Individuals of a population show polymorphism among themselves with respect to different characters. These variations could be both heritable and non-heritable. Because of variations, the different individuals in a population exhibit different performances with respect to various traits in a prevailing environment. For example, if different individuals in a plant species posses different heights, the taller plants will be at an advantage in getting more sunlight and pollinators due to extra exposure to these factors. Therefore, in the absence of a predator preferring the taller plants, tallness of plants will make them more competitive over dwarf ones; so more chances of survival of taller ones. During the struggle for existence in a given environment, heritable variations helping the individuals in grabbing the resources are selected over those which are not helpful. The individuals with favoured variations will survive and be able to produce their offspring inheriting the selected variations. This phenomenon was termed as survival of the fittest by Herbert Spencer, which Darwin considered equivalent to natural selection. Thus, natural selection is a condition prevailing at a given time that is responsible for differential abilities of individuals to survive and reproduce. Consequently, only the selected individuals with high rate of survival and reproduction are allowed to perpetuate and therefore the genes they carry will pass on to next generation. Gradually but continuously this changes the genetic composition of population over time, which is nothing but evolution. Since the direction of natural selection is usually not fixed but variable and it is a continuous and a slow process. So with every change in the environment, preference of individuals and therefore, the genes for selection also change causing accumulation of changes in genetic composition of populations. As a result of gradual accumulation of vast changes in the population, it may become totally different, a new species different from its ancestral population.

Evidences for natural selection

The process of evolution is very slow but continuous, and takes thousands to millions of years in bringing distinguishable changes in a large population. This makes the process of gathering evidences in support of evolution, a difficult task. However, biologists have come across a number of situations in nature where favourable changes have spread through a population in a comparatively short span of time, suggesting the progress of evolutionary process.

Industrial Melanism: One of the most spectacular examples of evolutionary changes witnessed by several scientists, particularly E. B. Ford and H. B. D. Kettlewell during mid of 20^{th} century has been the post-industrialization emergence and predominance of dark coloured moths in the industrial areas of England and Germany. During pre-industrial time, in early 1800s, the light-coloured variety of peppered moth (*Biston betularia*) was dominant at Manchester in England as it could evade predators (insect eating birds) by camouflaging on bright-coloured-lichen covered trunks of oak trees. On the other hand, dark form of peppered moth was at disadvantage as it could not evade the predators due to its prominence in such a background and therefore, comprised less than 1 percent of population in 1848. However, after industrialization of Manchester area, in 1898, dark form became dominant and comprised 95 percent of population because, sooty-black oak trunk had become protective to dark variety of moth. This dramatic change in colouration of moths has been termed as industrial melanism. This suggests that any change in direction of envrionmental factor, for instance, industrialization in this particular case, results in drastic changes in the composition of a population and thus substantiates natural selection.

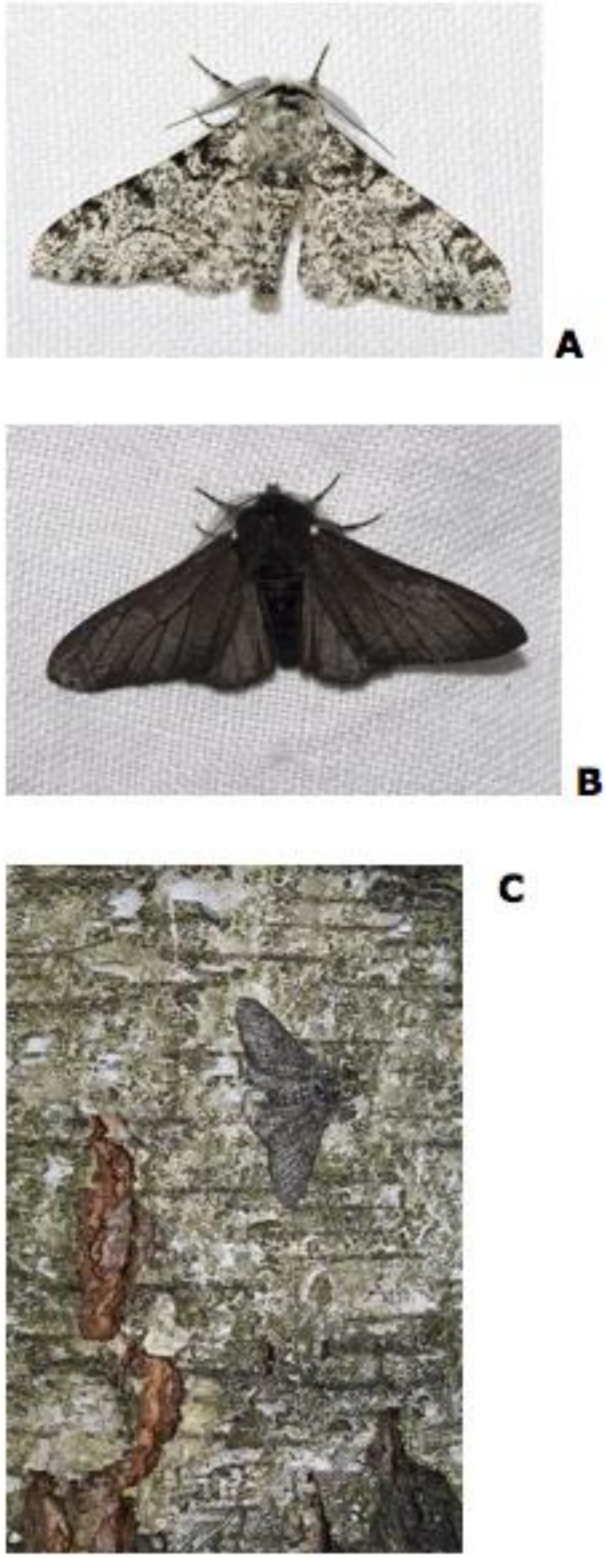
A
B
C

Figure : *Biston betularia* (Peppered moth) a) light coloured form (http://commons.wikimedia.org/wiki/File:Biston.betularia.7200.jpg) b) dark coloured form (http://commons.wikimedia.org/wiki/File:Biston.betularia.f.carbonaria.7209.jpg) and (c) dark coloured form on bark of birch (*Betula pendula*) tree (http://commons.wikimedia.org/wiki/File:Biston_betularia_20110529_103331_8099.JPG)

Changes in Guppy population in response to differential predation: John Endler and David Reznick studied wild populations of a small fresh water fish – Guppy (*Poecilia reticulata*), in different pools in the Arpio river on the Caribbean Island, Trinidad.

Figure : Guppy fish

Source: http://commons.wikimedia.org/wiki/File:Guppy-male.jpg

In one of the pools containing a small predator, killifish, which preys mainly on juvenile Guppies, it was observed that the average size of Guppies was large as they took longer time to reach sexual maturity. On the other hand, another pool containing a large predator, pike-cichlid that preys predominantly on large and sexually mature Guppies, had small sized Guppies attaining sexual maturity at younger age. In order to study natural selection, Endler and Reznick introduced a sample of Guppy population from the pool containing pike-cichlid to a new pool that contained killifish but no prior existence of Guppy population. For 11 years, they compared the age and size at sexual maturity of transplanted Guppy sub-population with the original population, and concluded that average size and the age of attaining sexual maturity increased in transplanted Guppy sub-population because, change in predator favoured large size as it helped in evading predation (natural selection).

Resistance against metal toxicity: Unlike animals, plants face more environmental stress due to their immobility. An interesting observation, related to natural selection in favour of metal tolerance, was made in algae. Aquatic plants cause a lot of economic problems for ship owners as such organisms have tendency to attach and grow on the bottom of ships that adds to the cost of scraping, extra consumption of fuel and loss of ship's earning during the time of scraping. To overcome this problem antifouling paint, which contains toxic compounds of copper, was developed and its application stopped the attachment of aquatic organisms. However, some species of brown alga- *Ectocarpus* sp. continued to grow on the hulls even after antifouling treatment.

Figure : The bottom of the sea hulls a number of marine species tolerant to copper are found these include the *Ectocarpus siliculosus* a common brown marine alga.
Source:http://www.serc.si.edu/labs/marine_invasions/feature_story/198035_1957571304175_1389511209_2325383_7149739_n%282%29.jpg
,http://commons.wikimedia.org/wiki/File:Ectocarpus_siliculosus_Crouan_(2).jpg

Therefore, the ships still needed to be scraped. Samples of *Ectocarpus silculosus* taken from the bottom of ship were shown to be tolerant to the concentration of copper ten times of what *E. silculosus* growing on a normal rocky shore could tolerate. So, within a brief period of time, the effect of antifouling paints has been reduced by the rapid selection of *Ectocarpus* sp. that can survive in the high local concentration of copper metal.

Lecture: Adaptive evolution- Natural Selection

Source: http://oyc.yale.edu/ecology-and-evolutionary-biology/eeb-122/lecture-3 (CC-BY-SA)

8. Neo-Darwinism

Darwin through his theory of natural selection postulated two important things related to evolution – first, evolution is a permanent process and all organisms have descended with modifications from a common ancestor and second, the natural selection is the primary mechanism of evolution. First postulate, as far as concerned, is now settled and biologists now consider it as one of the facts of the evolution. However, second postulate has still been open for discussion and time-to-time several objections have been raised about the mechanism of evolution. One of the major flaws of Darwin's theory was its inability to explain - how did the heritable variations required for natural selection appear? And, how did organisms transmit these variations to their offspring? Advent of Mendel's work on inheritance was initially thought to be contradictory to Darwin's theory of evolution as it proposed the particulate nature of inheritance instead of blending nature believed at that time. Darwin considered continuous variations to be the raw material for natural selection to act upon unlike discontinuous variations, which followed Mendel's pattern of inheritance. However, later on, continuous variations were also found to be following mendelian pattern of inheritance which are controlled by multiple genes that act in cumulative fashion. These discoveries and further advancement in population genetics helped reconcile Darwin's and Mendel's ideas and led to a new concept called Neo-Darwinism. Neo-Darwinism is also called the **Modern Synthesis** because it synthesizes or brings together classical Darwinism with modern genetic theory. It is based on work done by R. A. Fisher, J. B. S. Haldane, Theodosius Dobzhansky, Sewall Wright, Ernst Mayr, George Gaylord Simpson and G. Ledyard Stebbins. According to this theory evolution is an ongoing process in which genetic variations are introduced in populations at random by mutation and recombination. Populations evolve over time through changes in their gene frequencies brought about by number of causal agents such as random genetic drift, gene flow and especially natural selection. The accumulation of gene frequency differences, which takes place often gradually, eventually leads to more diversification among populations in geographically different localities. When gene exchange between racial groups can no longer occur because of reproductive barriers, separate species become established. The major tenets regarding the mechanism of evolution of Modern Synthesis are following:

1. Characters in living organisms are inherited as discrete entities called genes. Characters may be discontinuous (regulated by single gene) and continuous (regulated by multiple gene). More than one alternative forms of a gene are called alleles; sum total of these in a population constitute gene pool.
2. Populations contain heritable variations that generate at random. Different populations differ from one another on the basis of quantity and quality of variation (gene pools) present in them. Populations evolve with change in their gene pools.
3. Numbers of mechanisms of which natural selection is prominent one can bring changes in gene pools of populations. Because of activation of these mechanisms some of the variations are favoured over others. This causes differential abilities of survival and reproduction among individuals in a population at a given time, which consequently leads to evolution of population.
4. Under the influence of natural selection and other similar mechanisms diversification of populations take place due to gradual accumulation of small changes in their gene pools. This consequently divides a particular population into number of subpopulations. With passage of time subpopulations become reproductively isolated and stop inbreeding amongst themselves. This process is called speciation, which leads to origin of new species.

The modern theory of the mechanism of evolution differs from Darwinism in three important respects:

1. It recognizes several mechanisms of evolution including natural selection.
2. It recognizes that genes are responsible for inheritance of characteristics. Variations within a population are due to the presence of multiple alleles of genes.
3. It postulates that speciation is (usually) due to the gradual accumulation of small genetic changes. This is equivalent to saying that macroevolution (evolution

at or above species level) is simply a lot of microevolution (evolution at population level)

In other words, the Modern Synthesis or Neo-Darwinism is a theory about how evolution works at the level of genes, phenotypes, and populations whereas Darwinism was concerned mainly with organisms, speciation and individuals.

Population- the basic unit of organic evolution

As per Neo-Darwinism, evolution is a property of populations because it is the population rather than the individual that evolves over a time. Natural selection acts on the individuals but the effect is seen in changes in population. However, individuals due to their short life span cannot evolve but merely ensure continuity of changes to a population through offspring and therefore contributing to the evolution of the population.

A population is not a mere assemblage of individuals, but is a group of individuals which have coevolved and are capable of interbreeding and producing fertile progeny.

Figure : Black-tailed Godwit (wading birds) population.

Source: http://commons.wikimedia.org/wiki/File:Black_Tailed_Godwits_(5333964703).jpg

During evolution, the populations change genetically. The accumulation of genetic changes in a population, over a very long period of time, results into a new population and subsequently into a new species.

Like an individual, a population also has a genetic constitution, which is represented by its **gene pool**. The gene pool of a population is different from the genome of an individual belonging to it as genome of an individual depending on its ploidy level, can carry only few copies of a **gene** (alleles). For instance, a diploid organism can have only two alleles of a gene at any time. Whereas, the population to which that organism belongs, may have more than two alleles. The gene pool of a population is expressed in terms of frequencies of different alleles present.

Hardy-Weinberg Law

Regarding the allelic frequencies of different genes in a population, a very important observation was made independently by an English mathematician G. H. Hardy and a German physician W. Weinberg in 1908, which is now known as Hardy and Weinberg Law. This law states that the frequencies of all the alleles of a particular gene in an ideal population remains constant from generation to generation provided no any evolutionary force is acting on such population and individuals comprising such a large population have equal opportunities of producing offspring. Thus in a large and stable population, each allele has a constant frequency or proportion and sum total of all the allelic frequencies of a particular gene makes 1 or 100 percent.

Mathematically it is written as

$p + q = 1$

Where, p and q are the frequencies of a dominant allele and a recessive allele respectively, in a population.

If the organisms constituting the population are diploid, then the allelic frequencies will be

$(p + q)2 = p2 + q2 + 2pq = 1$

Therefore according to this law, each population has a unique genetic composition in terms of its gene pool and allelic frequencies of different genes, which differs from others. Further, the amount of variation present in a population does not change in an ideal population. When the genetic composition of a population changes it causes the evolution of the population. The Hardy- Weinberg law is based on an entirely theoretical population because the set of assumptions under which this law holds true can scarcely be fulfilled in any natural population. However, an understanding of Hardy-Weinberg law is helpful in recognizing the forces responsible for bringing evolutionary changes in a population. These forces are:

Genetic drift: One of the requirements of applicability of Hardy-Weinberg equilibrium is, a large sized population, because, the chances of repeated mating between two individuals increases as the size of population decreases. Therefore, the probability of fluctuation in genetic composition, in terms of gene frequency, also becomes greater. The phenomenon of any sudden fluctuation in allelic frequencies of a population purly by chance is known as genetic drift. Alleles may get lost or get completely fixed irrespective of the selective value. Sewall Wright gave the theory of genetic drift in 1930s and therefore, this phenomenon is also called as Sewall Wright effect. Due to restricted size of the breeding population, the gene pool of the new generation may not always be the true representation of the gene pool of parental population. In nature the population size may get reduced by number of means but two important means are given below.

(i) **Bottleneck effect:** Sometimes a population comprising of a large number of individuals, on exposure to a natural/unnatural calamity is reduced to a small population.

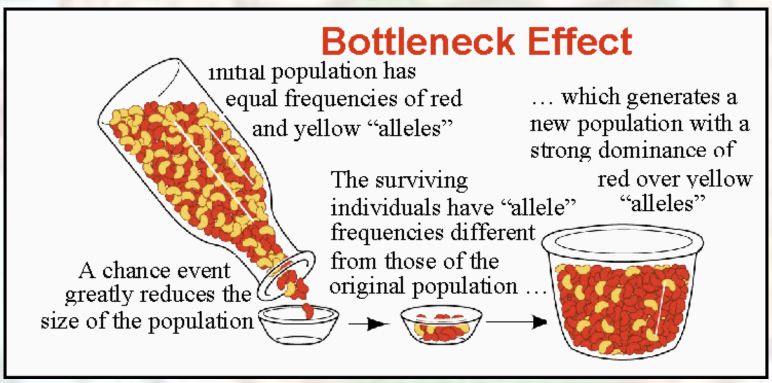

Figure : Bottleneck effect, an original population is reduced to small population due to sudden disastrous conditions (bottlenecking event) that may change the genetic constitution of new surviving population.

Source: http://1.bp.blogspot.com/-CJVZqejNip8/UTEj5yq4fxI/AAAAAAAAAjs/JBko30F6H_Q/s1600/bottleneckeffect.gif

The gene pool of such reduced population may not represent the original one, as the chances of over-representation of certain alleles and elimination of some other alleles becomes very high because of such disasters. The new population that arises as a result of interbreeding amongst leftover individuals will be genetically different from original population. Stebbins termed this phenomenon as bottleneck effect. For example, the population size of northern elephant seal in California (USA) reduced drastically to just around 20 individuals because of over hunting in 1890.

Figure : Northern Elephant Seal
Source:http://commons.wikimedia.org/wiki/File:Northern_Elephant_Seal,_San_Simeon2.jpg

In order to protect this species from getting extinct it's hunting was banned and over a period of time, the population of northern elephant seal increased to around 30000. However, the genetic diversity of the population was reduced since it involved the matings with only a few able males. This made the population susceptible to diseases etc.

(ii) **Founder effect:** Sometimes, a small group of individuals belonging to a large population invades a new territory either accidentally (by chance) or due to forced emigration. The first settlers called founders, which start a new population, have a very limited gene pool that may differ from the gene pool of the population from which they moved. Therefore, the resulting population will represent the gene pool of founders rather than the gene pool of population to which founders originally belonged.

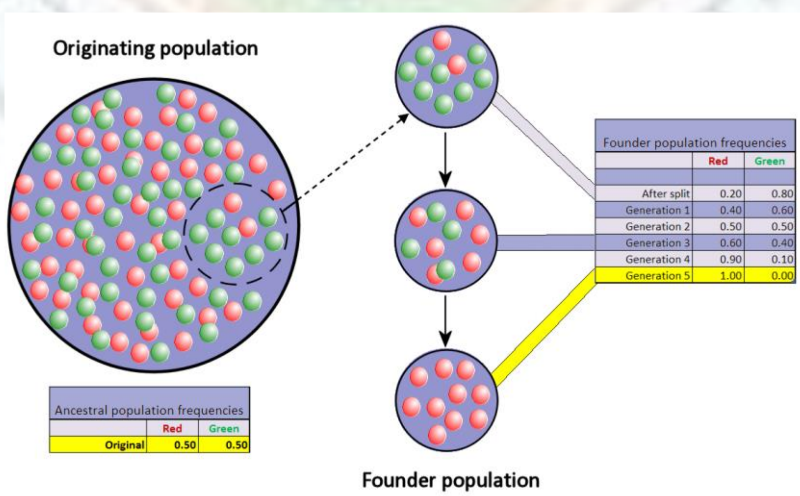

Figure : Founder effect, very small poulation differring genetically from original population colonize new habitate and evolves into a new population (founder population).

Source:http://upload.wikimedia.org/wikipedia/commons/d/d6/Founder_effect_with_drift.jpg
Moreover, the founders population being small in size, becomes prone to change in allelic frequencies as due to the process of random genetic drift some alleles may get completely lost, while other alleles may get completely fixed. In addition some of the alleles, which were disadvantageous in the environment of original population may become favourable in the new environment and hence favoured by natural selection. For example, the Collared Dove (*Streptopelia decaocto*) was confined to Danube but it extended its territorial range to Holland in 1947, to Belgium in 1952 and has now become a common bird throughout Western Europe and the British Isles.

Figure : *Streptopelia decaocto* (Collared Dove)
Source: http://commons.wikimedia.org/wiki/File:Streptopelia_decaocto_1280126_cr.jpg
The rapid spread of this species into previously uncolonized areas did not happen merely by chance but according to Mayr, who gave the concept of founder effect in 1956, this could have been possible only through genetic changes in the gene pool that provided a greater tolerance to lower temperatures and so enabled the colonists to survive. The founder effect is commonly observed in religious isolates of Human population who emigrated and settled in new places, for example, the Dunkers in the United States, are descendents of the old German Baptist Brethren who came to U.S.A. in early eighteenth century. This community has remained genetically isolated from other communities, due to its rigid marriage customs. Dunker community was compared with surrounding heterogeneous American population and the population in western Germany, from which the Dunker sect has emigrated three centuries ago, on the basis of frequencies of certain traits like blood group

types. The frequencies of many of these traits have been found to be strikingly different in the Dunker community from those of the general United States and West German populations.

Gene Flow: The genetic composition of a population may change by introduction of new alleles from other populations. The process is called gene flow. The natural populations are generally open and are found in a state of flux where migration of individuals is quite common. When immigrant individuals posses allele frequencies different from those of recipient population, redistribution of allelic frequencies takes place and a new equilibrium is set.

Mutation: Sudden inheritable changes that take place in the genetic material of any living organism are called mutation.

Figure : Mutations of coat colour in pet Rose-ringed Parakeets (*Psittacula krameri*)
Source: http://commons.wikimedia.org/wiki/File:Psittacula_krameri_-colour_mutations_-pets-8a.jpg

When change involves one or few nucleotides such mutations are called point mutation and when change occurs due to addition or deletion or change in orientation of a sequence of nucleotides, such mutations are called chromosomal mutations. Most of the mutations are found to be harmful to organism in which they occur and therefore in absence of any fixative mechanism such as heterozygosity harmful mutations are lost in same generation in which they are induced. In contrast, if mutations are either beneficial or neutral, such mutations may pass on from generation to generation in a population. This causes the accumulation of mutations and changes the gene pool of the population by altering the allelic frequency. Although mutation is the only mechanism known which is responsible for the introduction of new alleles in a population, mutation alone cannot change allele frequencies because of low rate of spontaneous mutations.

Selected Mating: When individuals in a population preferentially choose mates having specific traits and hence genotypes. This may result in non-random mixing of gametes as only selected genotypes get chance to reproduce. Consequently, this may lead to change in the allelic frequencies and therefore, change in the genetic composition of populations.

Natural selection: Because of their genetic differences, individuals in a population when exposed to a particular environment, under the influence of natural selection, show differential rates of survival and reproduction. Natural selection reduces the proportion of individuals having low relative finesses in populations. On the other hand, it increases the chances of gene- contribution by individuals with high survival rates to gene pool of populations. Natural selection is considered to be most important factor causing substantial changes in gene frequencies in populations. Majority of traits being under polygenic control are quantitative in their expression. When gradients measured of such a quantitative trait present in an original and a stable population are plotted against the number of individuals exhibiting the phenotype, a bell-shaped curve known as a normal frequency distribution curve is obtained. Any change in the shape of this normal frequency distribution curve is considered as an influence of some evolutionary force .

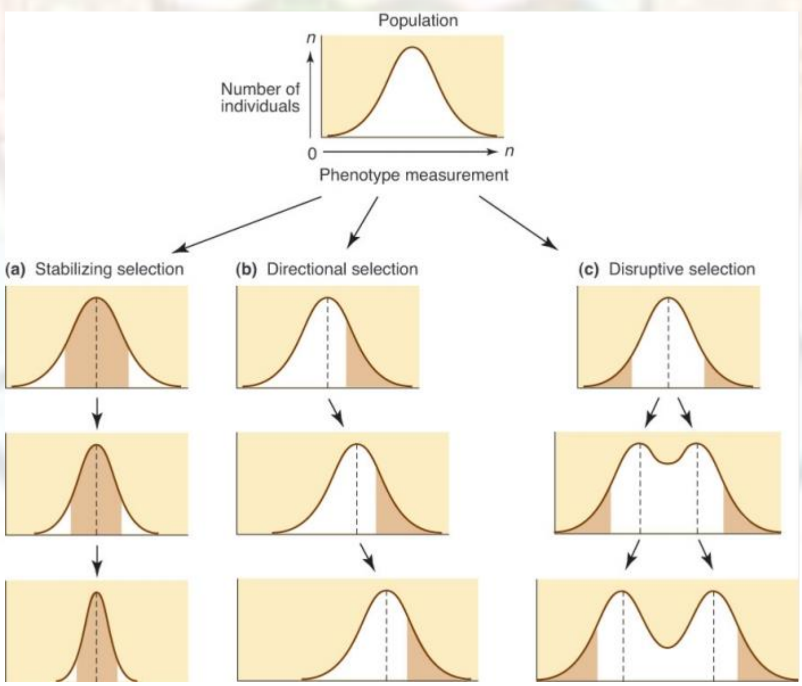

Figure: Frequency distribution curve of an ideal population and its exposure to various types of natural selection. The horizontal axis of each bell-shaped curve indicates measurements of a quantitative character and vertical axis indicates number of individuals possessing such measurement. Dashed lines indicate mean value and shaded areas represent the individuals selected as parents of next generation.

Source: http://i.imgur.com/ITk8J.jpg

On the basis of its net impact on a population, the natural selection can mainly be of three types.

1. **Directional selection:** In this, natural selection favours the individuals possessing one of the extreme phenotypes in a population. As a result, normal distribution curve is skewed in the direction of favoured phenotype due to shift in the mean value and phenotype initially occurring at one of ends of the distribution curve moves towards central region . Directional selection operates when environment is changed in one particular direction and favours the accumulation of those phenotypes that increase fitness of population in changed environment, and eliminates the unsuited ones. For example, the spread of resistance in bacteria and insects against antibiotics and insecticides respectively, can be explained on the basis of directional selection. Exposure of these organisms to toxic chemicals causes the death of sensitive ones and survival of few resistant ones. The resistant individuals quickly form a resistant population because of their short generation time. In one of the studies, a survey of mosquito (*Anopheles gambiae*) in the villages of Nigeria was conducted before **DDT** spray. It showed 0.4 to 6% of mosquitoes to be heterozygous for DDT resistant gene. However, after DDT spray, 90% of the mosquito populations were found homozygous for DDT resistant gene.
2. **Disruptive selection:** In this type, natural selection favours the individuals with extreme phenotypes located at both ends of normal distribution curve over the expense of individuals with intermediate phenotypes. It occurs when a population is subjected to divergent or cyclically changing environment that makes a variety of genotypes amongst a population most suited. This natural selection is also known as diversifying selection, because of formation of more than one peak of phenotypes adapted to different environmental conditions. Many small animals either live in a green background or a brown background as this provides camouflage to individuals in comparison to intermediate colour. European Swallowtail Butterfly (*Papilio macaon*) pupate either on green leaf or brown stem so, only two distinct pupa colours – green and brown are found without any intermediate colour.
3. **Stabilizing selection:** This type of selection favours the individuals expressing intermediate phenotype in middle of normal distribution curve and excludes those

with rare phenotypes. This happens when the environment remains relatively stable or unchanged on geological time scale. As a result the fitness of population reduces and population becomes homogeneous as selection discards the mutations . The birth weight of human babies is a good example describing stabilizing selection in action. In one of the studies at University College Hospital (U.K.), Karn and Penrose (1951) reported a direct relationship between the optimal birth weight (7.1 pounds) and optimum birth weight of 7.3 pounds at which infant mortality was lowest. Newborn infants less than 5.5 pounds and more than 10 pounds had highest mortality rate suggesting that natural selection favours mean birth weight.

Summary

Organic evolution is the process of gradual accumulation of genetic changes in populations of organisms through time that lead to transformation of species into new ones. It is an orderly and a continuous process, and is the cause of biodiversity observed on the earth. There are many theories of organic evolution of those gradualism theory is widely accepted. This theory considers organic evolution as a very slow and continuous process. Under the concept of gradualism on the basis of mechanism of evolution, there are two schools namely, Lamarckism and Darwinism. Lamarckism believes that due to change in environment, the living organisms in order to adjust according to changed environment, bring changes in themselves. Such acquired characters (variations) lead to origin of new species. In contrast to this, Darwinism believes that population always carry variations and any change in environment make some of these variations favourable. The favourable variations are selected by the environment (natural selection) and are passed to next generation. The gradual accumulation of those over a very long time results into origin of new species. The basic unit of evolution is population. Different populations have different gene pools and any change in the composition of gene pool of a population causes the introduction of variation in that particular population. As per Hardy- Weinberg Law the genetic composition of populations remain stable under ideal conditions. However, natural populations are always under the process of evolution. The gene pool of populations is affected by number of factors such as genetic drift, gene flow, mutation, selected mating and natural selection. Any sudden fluctuation in allelic frequencies of a population is called genetic drift, which occurs when a large population is reduced to small in number due to some disaster, Bottleneck effect, or due to emigration of a subpopulation to new territory, founder effect. The populations also change genetically when new genes are introduced from other population (gene flow) or they develop their own at random (mutation).

Similarly, selective interbreeding also changes the gene pool of populations over the generations. Amongst various factors responsible for evolution of populations, natural selection is most important as it results in differential capacities of survival and reproduction of genetically differing individuals in a population. Depending upon the types of individual being favoured by natural selection, it could be directional selection (if some extreme character is under selection), disruptive selection (if more than one extreme characters are under selection) and stabilizing selection (if most common character is under selection).

Glossary

Allele: an alternative form of a gene, different alleles of a gene occupy the same locus on homologous chromosomes.

DDT: dichloro diphenyl trichloroethane, a manmade insecticide.

Fossil : remnants of living organisms that died long ago.

Gene: a part of hereditary material that is the basic unit of inheritance and encodes some specific function.

Gene pool: Sum total of genes present in a population at a given time.

Genome: Sum total of genes present in an organism.

Open system:a system exchanging energy with its surroundings.

Population:a localized group of interbreeding individuals that Produce fertile offspring.

Reproduction:ability of living organisms to make their own copies.

Exercise/ Practice

Q1. Define the followings.

a) Organic evolution

b) Natural selection

c) Population

d) Gene pool

e) Genetic drift

f) Mutation

g) Speciation

h) Variations

i) Hardy-Weinberg Law

Q2. Write short notes on following concepts of organic evolution.

a) Lamarckism

b) Darwinism

c) Neo-Darwinism

d) Gradualism

e) Catastrophism

Q3. Differentiate between the following.

a) Lamarckism and Darwinism

b) Darwinism and Neo-Darwinism

c) Gene pool and Genome

d) Bottleneck effect and Founder effect

e) Disruptive selection and Stabilizing evolution

Q4. What are the salient features of Lamarckism? Critically examine this concept in the light of modern biology.

Q5. What is law of inheritance of acquired characters? How does it explain the elongation of neck in giraffe?

Q6. What is Darwin's concept of evolution? Discuss the observations made and deductions drawn by him, which helped in building this concept.

Q7. What is Neo-Darwinism? On what points does it differ from Darwinism?

Q8. Name the factors responsible for affecting the gene pool of populations. Write the significance of mutation in relation to variation present in a population.

Q9. Write a short note on the importance of Hardy-Weinberg Law in understanding the evolution of populations.

Q10. Write a short essay on natural selection and its major types.

Q11. Discuss some of evidences studied by you in support of natural selection.

Further Knowledge hunt

Search scientific literature and try to find out about following.

a) Deme

b) Neo-Lamarckism

c) Punctualism

d) Mechanism of speciation

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