NETAJI SUBHAS OPEN UNIVERSITY

STUDY MATERIAL

POST GRADUATE ZOOLOGY

PAPER - 1
GROUP : B

Taxonomy, Biodiversity and Conservation

PREFACE

In the curricular structure introduced by this University for students of Post Graduate degree programme, the opportunity to pursue Post Graduate course in Subjects introduced by this University is equally available to all learners. Instead of being guided by any presumption about ability level, it would perhaps stand to reason if receptivity of a learner is judged in the course of the learning process. That would be entirely in keeping with the objectives of open education which does not believe in artificial differentiation.

Keeping this in view, study materials of the Post Graduate level in different subjects are being prepared on the basis of a well laid-out syllabus. The course structure combines the best elements in the approved syllabi of Central and State Universities in respective subjects. It has been so designed as to be upgradable with the addition of new information as well as results of fresh thinking and analysis.

The accepted methodology of distance education has been followed in the preparation of these study materials. Co-operation in every form of experienced scholars is indispensable for a work of this kind. We, therefore, owe an enormous debt of gratitude to everyone whose tireless efforts went into the writing, editing and devising of a proper lay-out of the materials. Practically speaking, their role amounts to an involvement in invisible teaching. For, whoever makes use of these study materials would virtually derive the benefit of learning under their collective care without each being seen by the other.

The more a learner would seriously pursue these study materials the easier it will be for him or her to reach out to larger horizons of a subject. Care has also been taken to make the language lucid and presentation attractive so that it may be rated as quality self-learning materials. If anything remains still obscure or difficult to follow, arrangements are there to come to terms with them through the counselling sessions regularly available at the network of study centres set up by the University.

Needless to add, a great part of these efforts is still experimental—in fact, pioneering in certain areas. Naturally, there is every possibility of some lapse or deficiency here and there. However, these do admit of rectification and further improvement in due course. On the whole, therefore, these study materials are expected to evoke wider appreciation the more they receive serious attention of all concerned.

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NETAJI SUBHAS OPEN UNIVERSITY

PGZO – 1
Taxonomy, Biodiversity and Conservation

Group B

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UNIT 1 ❑ Definition and Basic Concepts of Biosystematics and Taxonomy

Structure

1.0 Introduction

1.1 Historical resume of systematics

1.2 Importance and applications of biosystematics

1.3 Material basis of biosystematics-different attributes

1.0 Introduction

Study of taxonomy in undergraduate and postgraduate courses was not strictly taken into consideration in many of our institutions probably till 1980. The correct meaning of many terms and sentences remained obscure to many students and teachers. The lack of interest in this very basic science therefore created no further impact in the student society. Still to day only few get involved in taxonomic work. It is true that taxonomic work in its current meaning is really the hardest pursuit even for a single species. Moreover people in planning are more interested in instant productivity in terms of money from research and forget the very need of any basic work life sciences.

The results of numerous biological researches may be proved to be faulty if they really face erroneous nomenclature of the zoological object worked upon. Thus the accuracy in naming or identification of organism needs utmost care. There are recognized organizations and institutes working upon various groups, which constitute only a fragment of the entire animal world, and hence many workers depend on foreign institutes for clarifications and identification. It is therefore an attempts to present this very basic chapter of biology in lucid and easier way as well as in a more acceptable manner to students.

Although there are many books and journals of taxonomy there are still some deficiency to clarify the principles, objectives and procedures in taxonomy. There should be more examples and data pertaining to real taxonomic characters to clarify the various principles and methods. Anyone can find various terms, old and new, which needs to be clarified in details. Many texts do not often clearly explain relevant points or some steps in mathematical explanations. Only repeated reading and keen study can make one understand these.

Taxonomy is the basic and the ultimate part of biology. Any work must start with the help of some sort of classification and can be completed after proper incorporation of data from all possible fields of research. So the declining popularity in taxonomy is now reversed and there is increasing effort by scientists to find out possible links in understanding the biodiversity. In fact, if properly understood, taxonomy will open up new vision about the diversity, relationship and evolution of animal kingdom.

Definition of taxonomy, systematics and biosystematics

Taxonomy

The study of animal diversity is unknowingly or broadly referred as taxonomy or systematics. Very often they are treated synonymously. Although they are very much related and interdependent there is a basic difference between these terms.

The pioneer plant taxonomist, de Candole (1813), coined the term *taxonomy*. As we know, *taxis* means 'arrangement' and *nomos* means 'law'. Therefore taxonomy clearly means arranging of organisms on the basis of some laws. To understand those laws and procedures of arrangement one should know the theory and then apply them. Hence taxonomy has been defined as "theory and practice of classifying organisms". This classification involves the identification, description, naming (to assign a binomial nomenclature) and finally to ascertain its classification status. In this way taxonomy is highly intermingled with both systematics and biosystematics. This popular definition may be expanded in today's thinking as to prepare a classification on the basis of data obtained from the study of variations- their causes and consequences.

Classification is a logical system that consists of several *categories* or *ranks* each of which contains some number of organisms such that by the name of a category we can immediately imagine about the structure and other aspects of those organisms. That the organisms are to be placed under a specific category requires the study of their relationships. The term relationship is vital and means phylogenetic and all biological relationships. Relationships emerge out of extensive study of species in question. That will show how they are related to each other and how they differ from others. This again will show the path of origin and evolution of the group. Hence *Zoological classification* "is the ordering of animals in to groups (or sets) on the basis of their relationship" (Simpson, 1961). Here ordering means arranging the animals into groups. Here a little more should be cleared about the term classification. It is the result of taxonomic studies. Because the taxonomist "classify" organisms based on certain principles and the end result is the classification.

Again classification is not *identification*. One identifies organisms or individuals and place them in a previously established *taxon*, which may even, be based on a single character. Therefore the process is purely deductive. But classification is quite different because in classification population of organisms is ordered at all levels by inductive procedures. It deals with and evaluates a multitude of characters to interpret their relationships on the basis of which a classification is done. Example is the identification of a fish or an insect on the basis of characters and to place them in a specified taxon. But if we say classificaton of birds or fishes the meaning becomes clear at once.

Systematics

Systematics was originally used to describe the system of classification prescribed by early scholars like Linnaeus (1735). This was later defined by Simpson (1961) as "the scientific study of kinds and diversity of organisms and of any and all relationships among them". The other simple definition by Mayr (1969) is "systematics is the science of diversity of organisms". Therefore study on systematics include quite a broader areas of research which include not only morphology and anatomy, but also genetics, behavioural aspects and population study (including population genetics, ecology and evolutionary biology). The unique properties of each species, common characters of certain taxa and the variation within taxa are the products of systematics that ultimately help to construct a phylogeny. Mayr's definition of diversity includes all theses aspects and reflects the 'all relationships' of Simpson's definition. Evolution and classification can only be achieved through variation. There may be genetically, developmental and environmentally induced variations.

For a better understanding of it may be recalled that systematics starts with taxonomic works and as a result of the taxonomic works, the information obtained about a group of organisms are analysed critically to understand the causes and the evolutionary pathway leading to the formation of those organisms. Therefore the study of inter relationships is of much importance and the various types of these relationships among different taxa reflect the degree of relationship of the species having a common ancestor, various forms of relationships are morphological, anatomical cytological, geographic distribution and ecological relationships (concerned with nutrient dependence, competition and many others).

Biosystematics

Biosystematics is basically said to be synonymous with systematics. The term was originally applied at species level to solve criticical cases with the help of data from cytogenetics and population biology and thereby to produce a system of classification. It is the assessment of taxonomic relationships based on the cytogenetical or biochemical data within an evolutionary framework.

Therefore many authors agree to clearly differentiate biosystematics and classical taxonomy. Biosystematics has also been given the name 'experimental taxonomy' while classical taxonomy is said to be 'orthodox taxonomy'. In biosystematics population and not individual are considered and their evolutionary characters are studied. In this sense it is *genecology*- the study that is concerned with the variations of genotype and phenotype of individuals in a population in relation to the ecosystem.

Therefore the various terms are somehow much interrelated and overlap with each other to an extent. Sometimes another term **neotaxonomy** is used to describe modern procedure adopted in taxonomy and thus previously described morphological species are now called biological species. Although most emphasis are given on morphological data which are easily recognized, some organisms need further analysis with the help of modern techniques and thus expanse of taxonomy of 19th century has been extended to biosystematics. The recognition of common ancestor is based on similarity or differences and these are not merely morphological but also cytological, embryological behavioural and many others. Use of electron and scanning electron microscopy opened up a new horizon in morphotaxonomy. However, biosystematics is definitely an extension of age-old taxonomy where scientists are more interested and more keen to pour further information of organisms from various experiments. From information of genetical studies inferences can be made about the ancestral history of a species and thus speculate speciation. This also indicates the growing interest in taxonomy and a better understanding of interrelationships and evolutionary mechanism. The word "experimental taxonomy" is used to separate earlier taxonomy (orthodox taxonomy) when most species were described and their interrelationships were analysed on the basis of morphological features. But the trend has changed in the last 50 years and emphasis is already given on all aspects, which are now the key words in the definition of biosystematics. It is a new word in true sense separate from morphotaxonomy and more related to "systematics" as defined earlier. The definition of systematics clearly indicated far greater span and biosystematics is a part of it.

Some of the many closely related terms used are *chemical taxonomy*- deals with taxonomic characters obtained from chemical analysis; *systematic anatomy*- to find out data from anatomical studies and *cytotaxonomy*- similarly the data obtainable from cytological studies. These all are part of one term- the biosystematics and the collective results of this study will help systematics of a group of organism (= population) and their evolutionary relationships.

1.1 Historical resume of systematics

Taxonomy started its journey from the onset of human endeavour to know the curious nature of the living beings. It is the basic and oldest biological science and is probably the most controversial one. It is still facing the dramatic attack and counter-attack by taxonomists who are trying to solve the great puzzle of origin and evolution of living things on the earth. Again the contributions of many naturalists and thereafter the taxonomist have provided fresh impetus to the newer generation scientists, particularly so after 1960s.

The typical taxonomy has changed over the past century and now has been enriched by the addition of newer information from many fields of research. The nature of taxonomy may change with the passage of time and development of newer fields of investigation. Particularly during the last three decades there was enormous input in the explanatory field of theories of taxonomy. There is still incessant effort to find out a most acceptable procedure to find out true line of descent and the lines leading to related groups. The newer lines of investigations are pouring down valuable data about organism and the ultimate aim of these numerous research is to unify them to concrete information about a population and their interspecific relations. Although little work has been done but gradually tendency towards this is growing fast. These can be explained only through the principles of taxonomy. So the new taxonomy is looked upon differently and newer nomenclatures are adopted. In this way systematics contributed to the explanation of diversity, evolutionary theory, population biology and population genetics.

In the absence of a scientific classification, however, ignorant natives were well versed about the nature of local population of animals and plants. Many authors provided the trend in the development of systematics. Simpson (1961) and Mayr (1982a) gave excellent history of the taxonomic development. Mayr named it as history of theories of classification and Mayr and Ashlock (1991) as history of taxonomy and the same reflects the concept and trend in systematics. The various phases are briefly mentioned below following Mayr (1969).

Phase I : Studies done by natives or tribals

As mentioned, local people can identify many living organisms and give their name. This trend has the origin from the beginning of mankind. Still today many tribal natives are better to identify as they are associated to that ecosystem and know the nature guided by their parents. They are often apt to identify the beneficial and harmful plants and animals better than many scientists. Even rudimentary classification probably existed long before. Some tribes of Asia and America used two parts in the naming of organisms. Therefore some sort of binominal nomenclature started prior to Linnaeus.

Hippocrates (460-370 B.C.) gave many names of animals but not classified them. Aristotle (384-322 B.C.), the father of biological classification, studied the fauna of Lesbos

Island and clearly proposed that the characters of a species depends upon the habit, habitat and structural organization. Many of his contributions are still in text books. According to his *Scala Naturae* animals should be classified on the basis of their 'perfection' into 'lower' and 'higher' groups which is now explained in terms of evolution.

Phase II : Contribution by Linnaeus

Aristotle's thought was the sunrise in the study of systematics. The inspiration is seen in the establishment of a higher classification by John Ray (1627-1705). Information on many aspects of the unthinkable number of animals came as a result of worldwide voyages and explorations. The Swedish naturalist Carolus Linnaeus (1707-1778) was most influential of this and later periods for his extensive works. In the 10th edition of *Systema Natuare* (1758) he introduced the binominal nomenclature and strongly favoured Aristotlian principle in classification. The thought of systematics still was far away because animals were thought to be created by God and the classification was the presentation of the creator. Actually classification was based on any character and through dichotomous key, which resulted in '*artificial classification*'. This was very soon realized by many workers later on. However, Linnaeus felt the need to create hierarchy and some of his classification were more natural, particularly insects.

Phase III : A century of slow me amorphosis

This period extends from publication of *Systema Naturae to Origin of Species* by Darwin. Lamarck (1744-1829) added some practical approaches in classification of invertebrates. Although Cuvier (1769-1832) made some progress in systematics, still depended on '*priory weighting*' of characters. There was a gradual decline in the popularity of Aristotlian principle of essentialism (to depend on fewer characters). Thus priory weighting metamorphosed into '*posteriory weighting*' by the trend to classify on the basis of totality of characters (an empirical approach).

Phase IV : The era of Darwinism

The contribution of Darwin actually revealed the meaning of systematics and also helped in the establishment of a natural classification. His theory of evolution saved taxonomists from *creating* taxa and inspired them to *discover* taxa through intellectual justification. He pointed that separation of taxa depends on branching and these taxa should be ranked on the basis of their different degrees of modifications. He also explained the importance of posteriory weighting and methods to identify them.

The other events of this period were describing endless species, classify them and also to search the synonyms. Later in 1920s genetics and population biology started to develop and compete with typical taxonomy of this period.

Phase V : Rise of population systematics

Taxonomy started to be reshaped in the light of population biology when species collected from different geographical and ecological niches exhibited small or large variation. A new term '*population systematics*' was applied to the study of infraspecific population. Another term was '*New Systematics*' by J. S. Huxley (1940) attached to the new explanation of species concept and more biological sense in taxonomic research. Later population genetics was added to this to make population systematics healthier. However, population systematics should be regarded as an extension of classical taxonomy (Mayr).

Phase VI : Cladistics and Phenetics-two new schools

Hennig's (1950, 1966) theory of classification (Cladism) and Phenetic method of classification of Sokal and Sneath (1963) were published almost simultaneously and they created a wave of rethinking of the theories of classification and phylogeny. Both have merits and demerits and very soon Phenetic method became less reputed for more of demerits. Cladism today, however, refined by the contribution of followers still is under experimental stage. It seems true that a blend of several approaches should be there without sticking to a particular method or theory.

1.2 Importance and applications of biosystematics

Taxonomic study has put much importance beyond morphology. Its extension is seen in field observation and critical laboratory analysis. All these studies depend on the availability of often sufficient number of live specimens and sophisticated instruments. It may be unusually awesome for rare groups. Some specimens can be handled for a short time in the year or they may take several years to complete a generation. Therefore we still find more interest on typical taxonomy and, if done religiously, may not be 'bad' enough.

In spite of all such difficulties, genetics, population biology and biochemical data have been proved worthwhile for numerous taxa. Some taxa or their characters sometimes give trouble (due to *homoplasy,* convergent evolution or parallelism) and biosystematics becomes quite helpful if not the only procedure. Evolution of species characters always follow a very well defined sequence of events of minor or major changes in nucleotide composition or changes in protein structure. It is true that numerous changes in the above have, however, proved to exert very negligible effect of the survival of tile extant form. But these changes are very useful to decide its evolutionary history of line of descent. Again, highly variable characters are normally of low weight and are unreliable as are the retrogressive characters.

Experimental taxonomy on genetical studies is mainly based on the assumption of a common gene pool for a taxon and this is sufficiently different from nearer taxon. The differences lying in the chromosome number, nucleotide content and sequence not only prevents natural hybridization but the same show some near ratio to its nearer taxon from which it has recently been separated. The same holds true for other data pertaining to biochemical research. Added to these are the various forms of chromosomal changes, which are unique event in evolution.

The kind of most of the macromolecules and metabolic pathways of many prokaryotes and highest evolved animals are strikingly similar. This is due to common descent of the pathway of their evolution and function. However all these show specificity at every taxon and scientists have proved those specificity as a key character to a taxon. For example the immunological data have been widely used now to determine kin from non-kin (Williams, 1964; Leone, 1964). Another method is blood-group genes (" immunogenetics") in the study of pigeon (Irwin, 1947) and primates.

Various types of electrophoresis are now every-day schedule to compare amino acids and many other macromolecules of related species and the data clearly provide valuable information on relatedness and probable line of descent. Most recent in this trend is the DNA matching. As all organ or system has its own rate of evolutionary changes, the same is obviously exhibited by these tests.

Behavioural features are so exciting and so much specific that a naturalist can immediately identify a species from the structure of nest or its call. The call of specific bird during specific urge are now analyzed and matched with previously identified wavelengths to understand the nature of the call. This is proved to be highly species specific and is significant to study their behaviour. New sibling species of frogs were discovered from the study of their sounds. Ecologists are depending on biosystematics to explain their research results.

All these discussions remind what Simpson (1945:1) stated "..(taxonomy is) the most elementary and most inclusive part of zoology, most elementary because animals cannot be discussed or treated in a scientific way until some taxonomy has been achieved, and most inclusive because [systematics] in its various branches gathers together, utilizes, summarizes, and implements everything that is known.

After the loss of typological concept of species and emergence of biosystematics, samples obtained from different geographical area found to contain various degrees of dissimilarities. This led to formulate *polytypic species* concept. Such studies gained importance and reached maximum height in 1930-1940. Now taxon is a population and a species is defined in more biological sense. They are treated as samples of natural populations. This in turn led to the development of population genetics. Therefore evolution at species level was explained in a new way and the outcome was the great synthesis in evolutionary biology.

Since all sciences are inter-disciplinary, we see that stratigraphic distribution of oil need the knowledge of Foraminifera. Therefore micropaleontology became important. Biological, chemical or other forms of insect control plannings need proper guidance from biosystematics. The great field of marine biology depends on the biosystematics for most of its activities. The comparative biochemistry and molecular information of so many organisms are finally shaped through biosystematics.

1.3 Material basis of biosystematics-different attributes

To find out the true nature of an animal both its taxonomy and systematics studies are undertaken to find out the following types of characters :

- **Morphological :** These are the external features related to anatomy, embryology, karyotype and various external characters including the structure of genitalia.
- **Physiological :** These are metabolic, serological, biochemical, various secretions and some of the sterility factors.
- **Ecological :** These are food, host, season and effects due to parasitism.
- **Ethological :** These are behaviour related to territoriality, courtship, mating and others aspects of life.
- **Geographical :** These are the characteristics of distribution related to geography and its inter-relationship.
- **Embryological :** Provides information of ancestral characters, some intermediary features or characters not existing in adult but are taxonomically valuable. These show many plesiomorphic characters which may or may be expressed in adult.

It is really tough to find all the above characters of a taxon. However, a diagnostic feature of a taxon not only differentiates a taxon but it also becomes a strong character at lower category. It also shows relationship, which is a key factor in systematics assessment. The morphological characters are the first available features to identify any animal and these dates back to humanity. Added to this is the study of genitalia and later on, the internal organization and their correlation to functional aspects.

Today biosystematics depends on the recording of as many possible characters as possible of live as well as long dead remains of animals. However specific tests are made according to the nature of material. Its expanse of study starts from submicroscopic level. Since many experiments are time consuming and expensive, morphological studies by naked eye, by stereomicroscope and such instruments still occupy major role in taxonomy. Added to this is the scanning and transmission microscopy to peep deep into structural details. The high magnification and resolution helped to understand more about finer details of structures, which were impossible by light microscopy.

> Use of SEM and TEM

The numerical taxonomy depends on characters as well as character states. The development of a character is governed by a definite set of nucleotides. Therefore a change in a character must be due to certain change in that locus. Such changes may be in different directions and different phenotypic or biochemical or other form of changes can be determined by experiments. These various changes of a character are the states of that character. Determination of phylogeny requires all possible data or such characters of each taxon. The data are obtained from adults as well as immature stages (embryological etc.) including eggs. Retrogressive modifications and other evolutionary factors may obscure adult's true nature.

> Genetical changes are important for study

With the advent of biochemical researches, there was more and more need for pure identification of animals. This has immense applied and economy oriented value. These activities helped a lot to add to the score of 'characters' of a species and thereby help in rising of biosystematics. Numerous techniques and sophisticated instruments are developed for quicker and accurate study of the constituent bio-molecules (enzymes, hormones and such others).

> Study of bio-molecules is an important tool in the study of biosystematics

Embryological studies on various stages of an organism proved to be a success many times and avoided confusions over so called new species. Many forms are so long lived like any natural organisms (during their developmental period) that many renowned scientists treated them as new taxa. Therefore study of embryonic details is well known facet in animal science. An example is the study of egg structure helped to solve the true sibling species under *Anopheles maculipennis* complex (Table-1). Similarly many identification procedures for sponges depend on embryological studies. Experimental embryology is also a quite old and interesting study that provides much information on the specificity of organism and thereby

> Embryological features show gradation of characters including ancestral traits

providing stable feature. The latter are used as the basis to draw conclusions on biosystematics and phylogeny.

Table-1

Sibling species of *Anopheles maculipennis* complex divided on the basis of ecological data

Species	Habitat	Hibernating	Non-hibernating
(a) *maculipennis*	Cool running fresh water	+	—
(b) *messeae*	Cool stagnant fresh water	+	—
(c) *melanoon*	Fresh water of rice field	—	+
(d) *atroparrus*	Cool brackish water	—	+
(e) *saccharovl*	Mostly stagnant brackish water	—	+
(f) *labranchiae*	Mostly warm brackish water	—	+

Earlier naturalists depended on ecological data to classify and identify organisms. Plato, Aristotle and their followers consistently stressed on this. This has gained importance to day specially to segregate sibling species. Very often ecology acts as yardstick for first hand postulation or instant identification and this often proved to be accurate. Same species inhabiting differing habitats may or may not show speciation in future although develops special structures. Similarly closely related species differing in many traits and inhabiting diverse habitats may have similar ecological characters. Therefore ecological characteristics may often put enough selection pressure of importance and they, thus, have good taxonomic value in judging a species. Briefly the changes in abiotic and biotic factors of the habitat from a habitat of its origin stimulate deviations from parental food habit, behaviour, reproduction and others. This is again conceived in the sibling species of *Anopheles maculipennis* complex which is clearly divisible on the basis of ecological data. Here the habitat is clearly governing the pattern of hibernation of the eggs (Table-1).

Ecological data help to segregate hidden species and may act as hand-book to identify species

Ethology is not new but the use of ethological data in biosystematics is a bit recent. However local people or naturalists have already recognized many such features that are much specific to an organism. Such behaviours are many, for example, production of pheromones, sound production (for many purposes), aggressive or submissisive behaviour, nest building, territoriality, mate selection, courtship and such others. The evolution of such activities is again imprinted in their genome and thus important taxonomically. Recording of

Ethology determines the instinct and learned behaviour of an organism

sound wave produced by a single species at different situations are now analyzed and they serve as perfect indicator of specific behaviour.

Proper survey of any species over a large geographical area always conforms with a definite pattern. All realms, although specified, have no sharp boundaries. The distribution pattern remarkably shows the route of dispersal, similarities in ecological conditions and gradation of climate, soil and other biotic and abiotic factors. On the other side, species distribution itself can predict the ecosystem to which they belong.

Geographical distribution pattern of species clearly indicates the nature of a species and predicts some facts about its ancestors

Species belonging to a geographical area also reflect the nature of their ancestors which also inhabited similar conditions. Thus ancestral-descendant relationships are related to geographical distribution. A rodent (hystricomorph) of South America seemed to be close to African porcupine. Later it was proved to have originated from separate ancestor (Woods, 1950). Much confusion in taxonomy was only solved through geographical analysis:

Effect of geography is exhibited by local variations in a species and hence they are important in the study of true nature of a species. Hence study of sympatric and allopatric populations becomes necessary to understand homoplassy, new developments or character gradients.

Physiological parameters, such as regulation of morphological changes in different stages of development and in life style of adult, i.e., the biochemical factors determining the adult activities are species specific. All these depend upon enzyme system and are ultimately controlled by genetic constitution.

However, such studies can only be done in living species excepting some specific and expensive tests on fossils. But these are not always permissible and there are many other obstacles.

Physiological activities depend upon coordinated activities of biochemical parameters

Physiological activities depend upon coordinated activities of biochemical parameters and, hence study of latter may reflect the type of physiology of a species.

Many important and common biochemical pathways in almost all organisms show similarities. This is due to common descent during organic evolution. However there are lots of parameters by which each species differs from its nearest kin and show specificity in organization and behaviour of bimolecules. Among many techniques to identify them possibly the most and widely studied is the immunological analysis. But this process is not free from demerits and newer techniques are coming up to solve them. The biochemical assay and their roles in taxonomy are discussed in chapter two.

UNIT 2 ❑ Trends in Biosystematics—Concepts of Different Conventional and Newer Aspects

Structure

2.0 Introduction

2.1 Chemotaxonomy

2.2 Cytotaxonomy

2.3 Molecular taxonomy

2.0 Introduction

As already discussed, biosystematics has its own array of working principles and procedures. Numerical taxonomy paved the way of high popularity of biosystematics as the former needs numerous characters of an organisms and uses computer to assess the phyletic position of an organism. There are many contributions by morphotaxonomy but there are limitations. Any character is known to be governed by the specific combination of nucleotides and their final expression depends upon a series of complicated non-genetic factors (endogenous and exogenous).

Therefore there was increasing demand on the availability of information related to structure and modifications of chromosomes, the nature and positions of genes and effects due to their changes. The effects of above changes were seen in their biochemical profile. Therefore correlation of these two aspects (or three) was necessary to study an organism properly. Now these features are expected to be very much specific for a species since these evolved through a long process of evolution and natural selection.

Trends in modern morphotaxonomy

However, it is also well known that morphotaxonomy has made a progress in the study of finer surface texture (external or internal) with the help of scanning electron microscope (SEM). Similarly the addition of transmission electron microscope (TEM) and fluorescence microscope have provided detailed features of various protozoan, pathogens, other prokaryotes and such organisms, different types of cells and their changes, tissue sections prepared through special procedures and such cases where light can pass through the material. Thus innumerable data on characteristic parts are available. This study is particularly important for the characters subjected to selection pressure such as bristles on head and wings in many insects and thus are useful in taxonomy.

Scanning electron microscope

SEM helps to identify the actual structural details, which, by light microscope, appeared different. This helps to vividly recognize the many types of fine structures particularly on the body of arthropods, which are of immense taxonomic value. For example, the *Argas* (tick) was re-characterized and a dichotomous key was prepared from the study by SEM. The world of invertebrate has been much benefited with the invention of SEM. SEM has a magnification from 50 to 10,000 times and a depth of focus of more than 300 times than light microscopes (Figure 1 and 2).

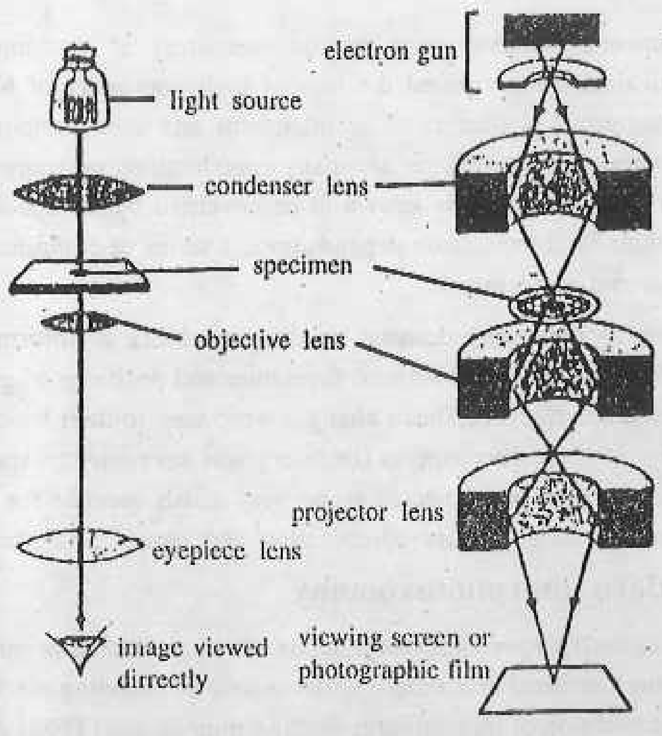


Figure 1. Different parts and pathway of light in light microscope (left) and transmission electron microscope (right)

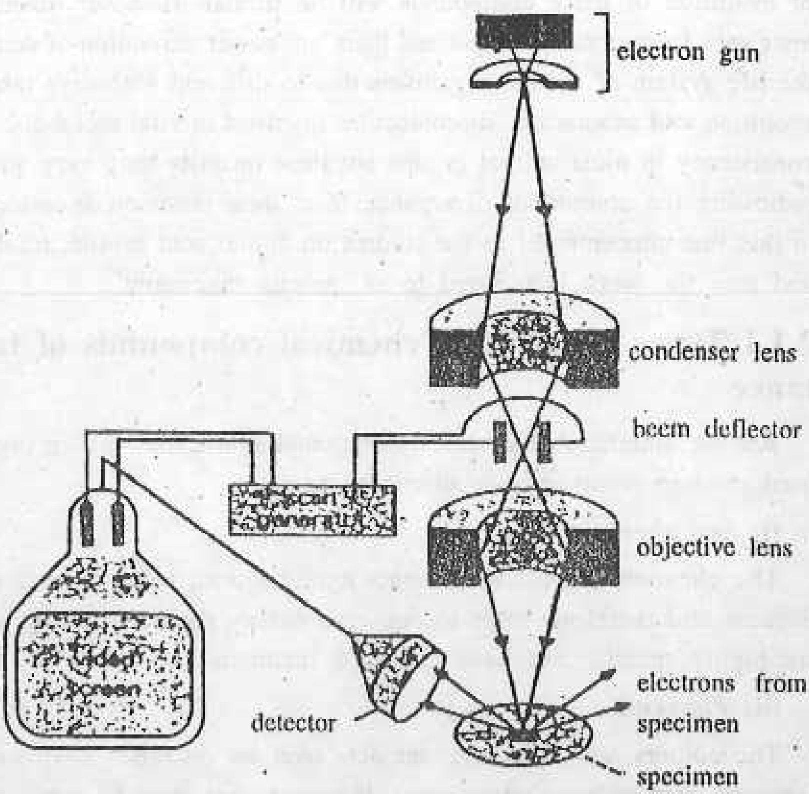


Figure 2. Different parts and pathway of light in scanning electron microscope

Transmission electron microscope

It has even higher magnification than SEM and is used to study further details of thin sections of tissues or organs. It helped in the identification *Amoeba* and *Thecamoeba*, some turbellaria, the egg-shell structure of certain Diptera (fruit flies). In comparison, SEM is more used in taxonomy than TEM.

2.1 Chemotaxonomy

Biochemical relationships among organisms reflect the relatedness and also help to determine the distance between the taxa. It has become very important to determine the chemical nature of constituents of organisms to differentiate very closely related species. In the absence of suitability of many other approaches, many taxonomists were compelled to search the biochemical differences. Both similarities and differences of some compounds are analyzed. It is true that many similar compounds will occur in many organisms as they have descended from some common ancestor at some time and the basic pattern of evolution of these compounds will be similar. However quantitative and qualitative tests vary from organ to organ and there are newer derivation of some compound to match the life system of certain organisms due to different pathways taken up by them during evolution and adaptation. Biomolecules involved in vital metabolic activities show nearly consistency in most animal groups but their quantity may vary widely in some relatives indicating the amount of divergence from their common ancestors. Most of the works in this line concentrated to the studies on amino acid profile, total protein, peptides etc. and thus the work is referred to as 'protein taxonomy'.

2.1.1 Types of common chemical compounds of taxonomic importance

Among innumerable chemical compound synthesized by an organism, the commonly used ones in taxonomy are discussed here.

(i) ***Sex pheromones*** :

The chemical signalling prevents hybridization, helps to find mate, indicates receptiveness and therefore helps to conserve energy during breeding season. Sex attractants are highly specific and have has good taxonomic value.

(ii) ***Pigments*** :

The colours and their arrangements over an organism have many purposes and are foremost data in morphotaxonomy. However, they may be confusing in mimetic forms. Sometimes they are temporary or change with age. The colour pattern helps mate identification or selection in sympatric species. The compounds necessary for colour production are attractive bio-molecules in taxonomic research. The notable colours of butterflies more easily identify them. The white and yellow pigments in Pieridae (Lepidoptera) are due to the presence of pterins. But mimicking unrelated forms develop similar colour by white flavones.

(iii) ***Animal toxins*** :

Animals produce toxins for self-defense, attack and to capture prey. These are subjected to vigorous research for medicine and thereby helped a lot in taxonomy. The works are in two ways, - to find the chemical nature and their effects on animal system. The chemicals are varied in nature and show convergent adaptations in many unrelated forms. For example, a mimetic chemical (argiotoxin) is found in orb web-weaving araneid spider and the other similar chemical (δ-philantha toxin) seen in bee wolf. Both the chemicals target the same receptor molecule in prey's neuromuscular junction.

(iv) *Neurotransmitter* :

Little work has been done on the phylogenetic distribution of neuroexcitatory chemicals in animals excepting those of Walker and Holden-Dye (1989). Beside acetylcholin as principal compound, many other specific chemicals are known to work in tandem on muscle activity. One important finding with no further explanation to its significance so far is the occurrence of L-glutamic acid as principal excitatory peripheral neurotransmitter in Chelicerata, Crustacea and Uniramia. It seems therefore that L-glutamic acid is an apomorphous compound with respect to acetylcholin showing monophyletic origin of those arthropods.

(v) *Lipids and hydrocarbons* :

The role of cuticle is many and some are prevention of water loss, gender recognition and identification of members of a colony. Those inhabiting in the nest of unrelated animals as symbionts or such are found to synthesize similar compounds. These compounds are easily extracted and identified chromatographically and show much similarity in related species. This compounds helped in separating cryptic species in some instances.

(vi) *Secondary plant metabolites* :

Plant taxonomists put much stress on seasonal or non-seasonal production of secondary plant metabolites. These compounds have many roles such as deter leaf eaters, as anti-fungal, anti-bacterial and others. Many plants shed leaves that contain waste substances. Among such many chemicals, the most important are the flavonoids, terpenes, diterpenes and alkaloids. The seasonal production of some compounds are due to seasonal gene expression and latter is governed by environmental factors. Many such compounds have economic value and thus took the attention of scientists who purified and analysed them. These studies again contributed to plant taxonomy and many names of categories are after these compounds.

(vii) *Pyrolysis product* :

Degradation of organic compounds in inert environment at high temperature is called pyrolysis. The volatile compounds can be separated by gas chromatography. The results are computerized and can be used in taxonomic matching with unknown samples. The data can also be used to measure taxonomic distance between species. This procedure is mostly used in identification of strains in microbiology.

Discussion

Presence of a set of chemicals in a species changes with age, sex, climate and many other factors. So taxonomic study with these data can only be suggestive and not deterministic. Chemical mimicry is an obstacle to confirmation of specificity. Many compounds take to different routes of synthesis. So construction of phylogeny of such compounds becomes a serious problem. Moreover a compound formed by a single or few gene expression cannot have much taxonomic weight than one morphological character because latter is the result of multiple gene expression.

2.1.2 Immunotaxonomy

With the immense progress in immunology, immunotaxonomy became a separate subject in taxonomy. From the days of Pasteur, immunology is developing day by day particularly in medicine as a principal tool in identifying antigens in many organisms. Molecules or mixture of molecules of an organism can initiate immunological reaction in a recipient. Such molecules (antigens) may be carbohydrate, lipid, protein, glycoprotein or such other compounds. The serum of recipient produces some specific proteins (antibodies) which binds specifically to the antigens to denature its activities. The quantity and stability of the antibodies produced in response to general immunoglobins (IgGs) depends upon the nature of the latter (antigens).

Antigen-antibody reaction produces an insoluble complex called *precipitin* and the latter is analyse both quantitatively and qualitatively. These data can be used in identifying relations between species (immunological distance).

Principles and techniques in immunotaxonomy

(i) ***Precipitin reaction***

A second antibody capable of precipitating the first antibody can precipitate a protein-antibody complex which is not completely insoluble or by addition of Protein A from *Staphyloccocus aureus* which has the property of cross linking IgG molecules can precipitate that protein.

Precipitin can only be produced when the quantity of antigen and antibody is in the ratio of 1:1.5; otherwise the complex remains in soluble state. Nuttall and co-workers (1904) obtained different kinds of serum proteins and glycoproteins by using whole blood serum as antigenic mixture. The quantity and quality of these compounds were studied and used as specific value for that particular organism. Similar such tests can be carried out in related or unrelated organisms and the values can be utilised in taxonomy as direct data of immunological distance. More similarity with data represents more similarity in their amino acid sequence. Differences in value or its wider difference means degree of separation of taxa and this also shows amount of amino acid replacement or loss.

Human serum → Rabbit → Anti-human serum

	Human Serum	Chimpanzee serum	Baboon serum	Dog serum
Anti-human serum	Maximum precipitation	Nearly Maximum precipitation	Nearly half amount of precipitation	No precipitation

Checker board shows relatedness among some mammals on the basis of quantity of precipitation. Higher the amount of precipitation more closer the two taxa are.

(ii) *Immunodiffusion*

When soluble antigens diffuse from a homogeneous solution into an agar gel, there is a continuous fall of its concentration from starting edge to final end to a value of zero. Somewhere along this concentration gradient is the concentration of antigen that gives equivalent concentration of the antibody.

In double diffusion technique (Ouchterlony, 1953), an antiserum is raised in an animal in response to an antigen or antigenic mixture. In a suitable gel medium, a central well and several other test wells are placed concentrically at a distance of few millimeter from

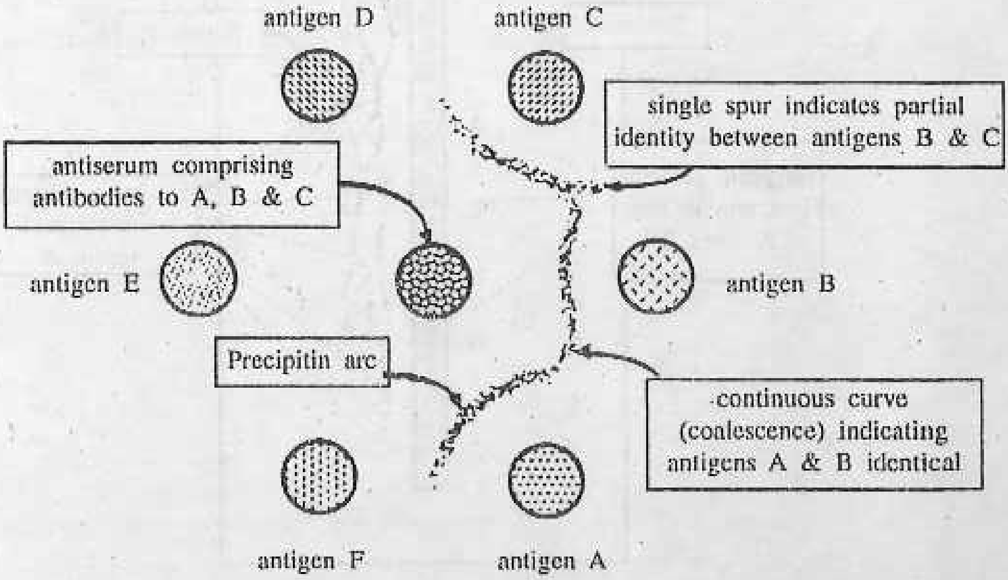


Figure 3. Immunodiffusion: arcs of precipitin showing degree of identity among antigens

each other and also from central well. Now antisera containing antibodies to test antigens is taken in central well while test antigens in peripheral wells. The antigens and antibodies diffuse into gel and depending on molecular sizes, will move up to a certain distance from their wells where precipitation will be formed (samples A-C). If there is no precipitation, then there will be no curved lines indicating mismatch between antigens and antibodies (samples D-F). Today patterns are cut in agar layers on microscope slides with stainless steel cutters. This process uses very small quantities of antigen and antisera and results are obtainable in a few days (Figure 3).

(iii) ***Immunoelectrophoresis***

This process has finer resolution in identifying complex mixture of antigens. Here antigens are first separated on the basis of their net electric charges and then visualized by precipitation reaction.

After electrophoretic separation, the median longitudinal well is filled with antiserum raised against one of the antigen samples. Both antigens and antibodies diffuse till they meet to form precipitation arcs. Since there are antigens of varying molecular weight,

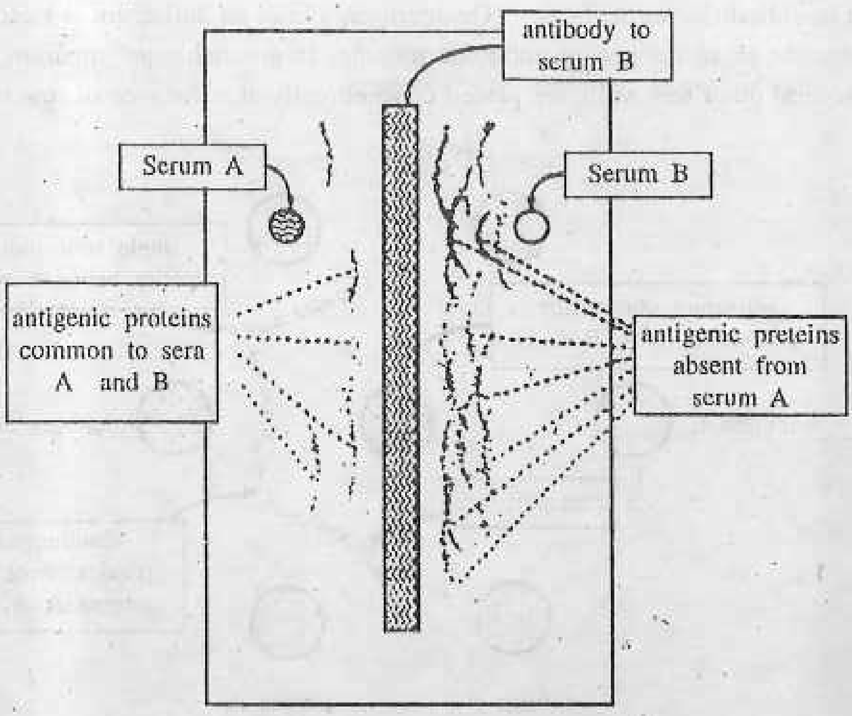


Figure 4. Immunoelectrophoresis to compare antigens of two taxa A and B.

there will be different mobility and these will create separation arcs separated longitudinally and also in width. The number of arcs on two sides clearly demonstrate the relatedness or distances and the difference of total arcs on two sides is the immunological distance between the two taxa. This technique detects the purity and the particular antigens in sera, culture filtrates, tissue or cell extract (Figure 4).

(iv) ***Immunofluorescence***

Fluorochromes (dyes) exposed to ultraviolet, violet or blue light become fluorescence or emit visible light. These dyes (examples rhodamine B or fluorescein isothiocyanate) can be fixed to antigen or antibody.

In direct immunofluorescence, microorganisms or cells (containing antigen) is fixed on a slide and then treated with fluorescence labelled antibodies. When viewed under fluorescent microscope, the pattern of fluorescence reveal the location of antigens in that cell. This is used in microbiology to identify surface antigens.

Indirect immunoflurescence is done on serum of an organism infected by microorganisms. A known antigen is fixed on a slide and allowed to react (if occurs at all) with test antisera to form fixed antibody. Now fluorescein labelled antiimmunoglobin reacts with fixed antibody. The presence of test antigen is observed if there is any fluorescence.

(v) *Radioimmunoassay*

This highly sensitive modern technique requires only picogram quantity of antigen of test organism. A soluble and purified antigen labelled with radio-isotope and test antigen is allowed to compete for the binding sites of an antibody. At equilibrium in the presence of an antigen excess there will be both free and labelled antigens. Therefore, if concentration of test antigen is high, it will bind more with antibody and there will be less amount of bound activity. Here some of the exposed sites of the antibody will be taken up by labeled antigen during complex formation.

[TA] + [SA] + [AB] → [TA | AB | SA]

[Test antigen (TA) at higher concentration than SA (labelled antigen) will show fewer radioactivities in antigen-antibody-antigen complex]

Radioimmunoassay is the only best choice where very limited amount of antigen is available for study as in case of fossil (Westbroek et al., 1979). In general radioactive iodine (^{125}I) is used which means cost and risk in such experiment. The major advantages of this techniques are that it detects any pure antigenic compound; it is highly sensitive and specific and it requires minimum handling and data processing. The disadvantages are that it is costly, requires some chemicals that have limited half-life, radioacitivity problems and takes days to complete assay.

(vi) *Microcomplement fixation (MC'F)*

This method helps to identify the amount of sequence divergence in the particular antigenic protein. The concept of this procedure is that a given protein has few separate antigenic sites (20 or more). Such a protein is purified and a polyclonal antibody is raised in a suitable organism. Any antibody of this will definitely recognize antigenic sites of that protein.

Complement or complement system is composed of at least 17 complement protein and they act in a cascade. They are activated after antigen-antibody complex has formed. And this serial phenomenon of complement binding with antigen-antibody complex is called complement fixation. A fixed amount of complement is added to antigen-antibody complex and only that amount of former will be used up which binds with the complex (that is proportional to the number of antigenic determinants). Actually after reaction, the amount of free complement is measured. This is done by allowing it to lyse sheep R.B.C. that are previously coated with anti-sheep R.B.C. antibody.

During divergence of taxa that protein also show deviation and has lost some or all antigenic sites and this will be shown by the divergence of amino acid sequences. Therefore antibodies in the mixture (polyclonal) will show some to bind to their specific antigenic determinants, which still persist in that protein of those taxa. A change or replacement of even one amino acid will affect antigenic determinant and thereby prevent antibody attachment (Maxson and Maxson, 1990).

MC'F procedure requires purification of antigenic protein from two or more species, raising of respective polyclonal antibody, preparation of standard complement fixation curve and similar curves between same antibody but different antigens. Differences in the amount of complement fixation are the measure of dissimilarity between two antigens (= two taxa).

Maxson and Maxson (1990) obtained different ID values proportional to amino acid replacement. The immunological distance (ID) is equal to 100 $\text{Log}_{10\,x}$ (heterologous antibody titer/homologous antibody titer).

(vii) ***Hybridomass-Production of monoclonal antibody***

Gearges Kohler and Cesar Milstein (1975) developed hybridomass which is obtained by membrane fusion (with the help of polyethylene glycol) between spleen cells and myeloma cell. A rat is injected by a specific antigen so that B cells of rat produce antibody. Then the spleen cells are fused with myeloma cells (cancerous cells not able to produce immunoglobulin). These cells are now called hybridomass, which is tested for the production of desired antibody. The cells are uniform, specific and can be readily produced in large quantity.

Monoclonal antibody, unlike polyclonal antibody from hybridomass detects specific antigenic site on protein, if present, from different taxa and can be used in parsimony analysis. But this process requires commercial production of more monoclonal antibodies and this is costly and time consuming (Greenstone et al., 1991)

Remarks

Many other immunological methods are employed in research particularly in medicine. Some of these are Enzyme Linked Immunosorbent Assay (ELISA), Immunization and Transplantation Rejection. There are also some types of spectroscopic analysis such as Spectroscopy, Nuclear Magnetic Resonance Spectroscopy (NMR), Optical Rotatory Dispersion (ORD), Infra Red Spectrometry (IRS), Atomic Absorption and Flow Cytometer. These are now commonly used as modern techniques to identify macromolecules and the data can even be used as specific characters of taxa and thereby can be used to calculate similarities or dissimilarities among taxa. ELISA is relatively cheap to operate, lacks radioacitivity hazards and suitable for small laboratory. Raman spectroscopy is helpful to determine intermediate sized molecules such as small peptides, pollutants, metabolic intermediates and substrates.

2.1.3 Applications of chromatography

(i) *Ion Exchange Chromatography*

This process separates amino acids and proteins by their presence of negative or positive charges when passed through a column of ion-exchanger (compounds like polystyrene) in presence of specific pH. Generally anionic buffers like Acetate, Barbiturate and cationic buffers like Tris, Pyridine etc. are used in this experiment.

(ii) *Affinity Chromatograohy*

Purification and separation of any macromolecule such as protein, enzyme, mRNA can be done by passing through a column containing substance that binds with the sample compound. For enzyme a ligand and for protein antibody is selected for this purpose.This method helps better purification within a short period.

(iii) *Partition, Adsorption and Gas Chromatography*

A substance is shaken in two immiscible liquid phases in a separating funnel. The substance, upon shaking forms two phases; if one phase is allowed to move, the substance will also move on the basis of its partition coefficient. The movement will be rapid if the sample prefers mobile phase or will be slower if it takes stationary phase. The rate of movement depends upon the intensity of characteristics of adsorption. Silica gel, aluminium oxide, cellulose etc, are used as adsorbent.

In gas chromatography, a gas acts as mobile phase. A non-volatile liquid acts as stationary phase and is the coat of the matrix substance of the column.. The principle of separation is the differences in partition coefficient of the volatilized compound between gas and liquid phases. Both qualitative and quantitative analysis of many compounds is done by this method.

2.2 Cytotaxonomy

The study of chromosomal complement of a cell or organism (Karyotype) is recognized as a taxonomic character for a long time. But the study so far yielded little information in taxonomy in spite of its wealth of data. Cytotaxonomy in broader sense includes major chromosomal changes and also those changes of few nucleotides. Both of these changes essentially change the genome, either the number of chromosome is altered or sequence of nucleotide is altered. Addition or subtraction of whole chromosome is frequent in plants while it is rare in animals. The chromosomal rearrangement that took place during natural hybridization between different karyotypes has contributed to the evolution of many organisms with the present day genome. Many other innumerable combinations must have taken place and later deleted by natural selection.

(i) ***Karyotype analysis***

The haploid chromosome number in animal may be even 1 in *Myrmecia* (ant) up to 250 in some fern. The chromosome number usually does not vary much in related species. While in Lepidoptera and many organisms the number shows consistency, in *Myrmecia* this is found to vary widely from 1 to 42 (Imai and Taylor, 1983). This number varies from 2n= 4 (*Haplopappus gracilis*) to 2n= 530 (*Poa litterosa*). In some closely related plant species, the number increased in multiple of a haploid number. For example, this number is 7 and the species were found to have chromosome numbers as 2n= 14, 28, 42, 56, 70 etc. This doubling, tripling onwards of basic number is called polyploidy. Opposite to this, in some plants, there may be loss of one or more number of chromosomes (aneuploidy). It is observed that the karyotype of members of same species remains fairly constant. This is most chosen tool in cytotaxonomy and also used in phylogenetic reconstruction.

However, sometimes one or few parts of a chromosome or even a whole chromosome may be lost or doubled showing enormous changes in the offspring. Many processes may bring about changes in chromosome number. These are chromosomal deletion, duplication, inversion, fusion and fission. Among these, overlapping inversion is widely used to detect phylogeny. By suitable staining method, chromosomal rearrangements can be detected and these data are used as characters for a species. A cross between species with normal chromosomes and another with major change in its chromosomal arrangement will show reduced fertility due to unbalanced genome. But in many *Drosophila* and Grasshopper, unrelated species with enough differences in morphology of chromosomes show little or no reduction in fertility. White (1982) explained these as exceptions and no further explanation is so far available.

Any form of chromosomal rearrangement in an offspring will produce ephemeral population if that particular arrangement is disadvantageous. Sometimes, however, such disadvantageous heterozygotes may produce stable population under condition of enough time to undergo inbreeding. Chromosomes may break at certain points along the length and afterwards join at any point. So there may be many combinations of chromosomal rearrangements. A reversal, ie., back to parental configuration is an unlikely event in evolution of a species. In practice, identification of similar but non-identical inversions is not an easy task although that may be associated with other evidences. Farris (1978) suggested that polymorphism in a population can occur for that inversion which may or may not be selected by nature.

(ii) *Chromosome banding*

At finer level, individual chromosomes and their homologous are thoroughly studied in several species for their morphological and biochemical properties. These characters are found to be fairly consistent indicating specificity. Excepting few results, this part is still at research level in cytotaxonomy. The study involves identification of banding pattern, differences in densities of chromatin and heterochromatin, ratio of A-T and G-C content and total number of chromosomes with regard to position of centromere (i.e. number of metacentric or acrocentric or telocentric chromosomes).

Banding pattern identification solved separation of cryptic species and indicated their phylogeny in Simulidae (Diptera) that contains many important vectors of tropical diseases (Dunbar, 1966). However, the easiness in the study of Diptera (also in Collembola and Protista) by the presence of polytene chromosomes is not available in most other organisms. Special techniques, such as C-, G- and Q- banding methods are employed in cases with polytene chromosomes and revealed translocation and other chromosomal changes and homologies with related species. All these data were incorporated to cladogram preparation.

(iii) *Chiasma frequency*

This frequency is very much specific for a species and hence used in taxonomy. The chiasma is genetically controlled and seen in diplotene stage of meiosis when genetic exchange occurs. It depends basically upon the extent of homologies of sister chomatids. Therefore normal number of chiasma will be found in con-specific members only.

(iv) *DNA hybridization*

Since all expressed characters are due to the sequential arrangement of nucleotides within expressed genes, any change in their position will alter those characters partly or wholly. Few to many nucleotide may change or lost to affect a character. The differences between two species can be measured by the amount of genetic differences between them. This is actually the amount of nucleotide difference, that is, the unpaired portions of

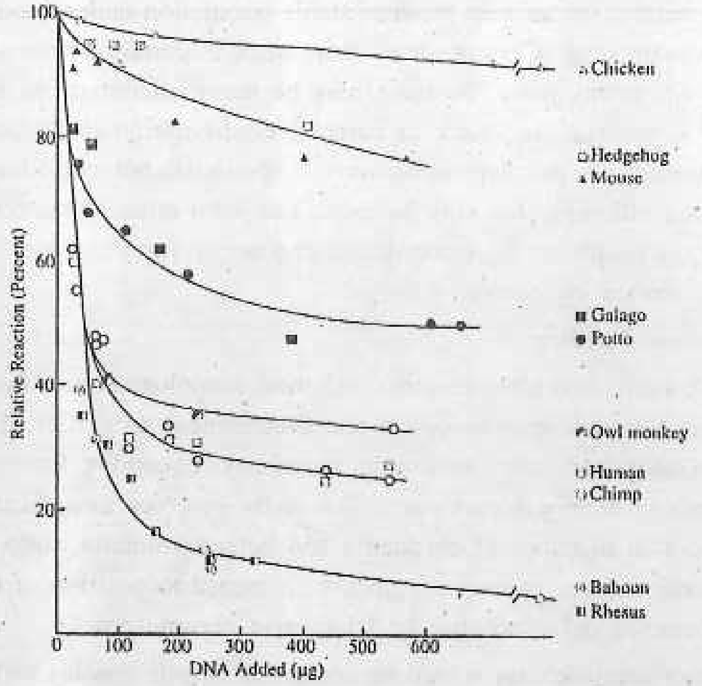


Figure 5. Relative similarities in DNA sequences in some animals

nucleotide when allowed to hybridize. This can be measured in two ways: one is the amount of DNA of two species that actually hybridize and the other is the amount of complementary DNA in the hybrid molecule. Such experiment shows the relatedness in mammals clearly (Hoyer and Roberts, 1967) (Figure 5).

One of the various methods of DNA hybridization is to allow two types of single stranded DNA to hybridize. The duplex is then denatured at increasing temperature at 1° C at every few minutes. The resultant single strand DNA is collected at every new temperature and the proportion is plotted against respective temperature. Now the dissociation curve of hybrid DNA and control DNA is compared. The thermal stability (TS) is that temperature at which 50% of the duplex DNA has dissociated. The difference

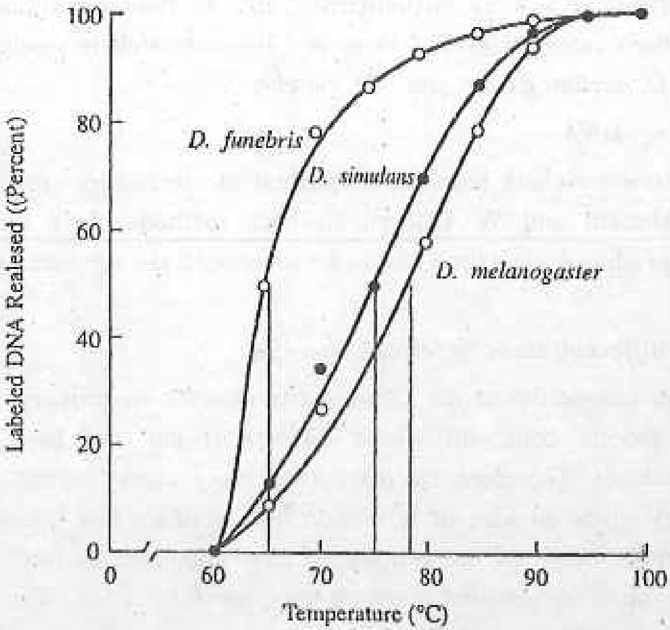


Figure 6. Comparison of thermal stability of DNA among three species of *Drosophila.*

(ΔTS) between hybrid and control is directly proportional to the amount of unpaired nucleotide in the hybrid DNA. It was found that for 1° C, the ΔTS is equal to 1.5% mismatched nucleotide pairs (Laired, McConaughy, and McCarthy, 1969) and the more presumed value is probably for 1° C, the ΔTS = 1% (Figure 6).

(v) *DNA phylogeny*

Hybrid DNA always tends to dissociate at a temperature lower than their parents. This is constant for that hybrid molecule and is called *thermal stability* profile, which indicates rates of nucleotide changes per unit time. Therefore this is an important tool in diagnosing degree of differences between two species under study. 3H- labeled DNA of *Drosophila melanogaster* and DNA of other species were hybridized and their thermal stability was measured and the values were:

Drosophila melanogaster (Homologous duplex) TS = 78°C

D. melanogaster + *D. simulans* (Heterologous duplex) TS = 75°C

ΔTS = 3°C

D. melanogaster + *D. funebris* (Heterologous duplex) TS = 65°C

ΔTS = 13°C

Therefore hybrid DNA's of *D. melanogaster* and *D. simulans* are noncomplementary in about 3% of their nucleotides and there is 13% mismatch in nucleotides in case of hybrid DNA of *D. melanogaster* and *D. funebris.*

(vi) *Sequencing DNA*

This can be done by chain termination method of F. Sanger or chemical cleavage method of A. Maxam and W. Gilbert. In both methods, four sets of radioactive oligonucleotides produced from the DNA to be sequenced are subjected to high resolution electrophoresis.

(vii) *Genetic differentiation by electrophoresis*

Electrophoresis cannot detect all amino acids changes in primary structure. Due to peculiarities of genetic code, all allelic differences can not be detected by their corresponding proteins. Therefore electrophoresis truly cannot detect genetic variation perfectly and only gives an idea of it. Hence few arbitrary loci are selected for study which act as representative of the genome of that organism. A few such homologous loci in different taxa are studied through proteins they code. The average genetic differentiation observed in the samples will represent the genome. Thus the differentiation over a number of loci is approximately proportional to the time since their last common ancestor and this view help to construct the phylogeny. The data will also show *Genetic Identity* (I) and *Mean Genetic Distance* (D) as follows:

$$I_1 = \Sigma(a_i \times b_i) / (\Sigma\sqrt{a_i^2} \times \Sigma b_i^2)$$

I_1 is the genetic identity of a locus I; a_1 and b_1 are the frequencies of i-*th* allele in population A and B. $I_1 = 1$, if two populations have same alleles in identical frequencies and $I_1 = 0$, if they have no alleie in common.

Mean Genetic Identity (I) = $[J_{AB}]/[\sqrt{(J_A} \times J_B)]$

J_{AB}, J_A and J_B are the arithmetic means, over all gene loci studied, of $\Sigma(a_i \times b_i)$, Σa_i^2 and Σb_i^2 respectively. Here I = 1 (complete genetic identity) or may be I = 0 (complete genetic differentiation).

D = – $\log_e$ I (D = 0 – infinite; 0 means no genetic differences.)

It is believed that nucleotide substitution occurs independently and this follows Poisson distribution, then D is equal to average number of electriphoretically detectable nucleotide substituion accumulated in that taxa since it has separated from common ancestor. The *willistoni* group of *Drosophila* consists of six closely related and morphologically alike species and these has been separated by electrophoresis at 36 loci.

(viii) *Pulsed Field Gel Electrophoresis (PFGE)*

Here at first, Gel electrophoresis of DNA cut with restriction enzymes followed by specific hybridization is done and the fragment sizes are measured. The method can separate DNA with 50 kb size. But when direction of electric field is periodically (pulse) changed, the power of DNA separation increases (Schwartz and Cantor, 1985).

(ix) *Spectrophotometric technique*

Most compounds absorb light in visible wavelength or ultraviolet region. Each compound shows different absorption at different wavelengths of light. This values constitute the absorption spectrum for that compound. Its value for nucleic acid is 260nm and proteins 280nm. The difference is due to the presence of more unsaturated rings in nucleic acids.

2.3 Molecular taxonomy

Comparative taxonomic analysis of various bio-molecules can be done by various methods as described earlier. Molecular taxonomy deals with identification, sequencing, analyses and importance of proteins and nucleic acids along with some related and specific techniques.

Due to common descent, similar compounds will occur in many organisms and these are dealt as conservative molecules. Still some chemicals show gradual or rapid changes during evolution and these rates are important in phylogenetic research. Again quantitative and qualitative tests of biomoelcules which are expected to deviate from ancestors by the differences in physiological activities can be made to measure the extent of divergence. Recently much attention has been given to sequencing of protein, nucleotide, and correlation between the two.

The analysis is usually done in two ways, viz. quantitative and qualitative studies of biomolecules. The amount and kinds of different protein, the constituent amount and kinds of amino acids of these proteins are identified and the values are compared among related taxa. The resultant values are then numerically arranged into data matrix and the phenogram or cladogram is prepared. This type of analysis was done to construct the phyletic lines of some groups or animals. For example, a study on the location of synthetic activity and amount of L-ascorbic acid in birds shows that it was synthesized in kidney only in most birds. Later, in a few advanced groups, liver also took responsibility for its synthesis and it is absent in modern Passeriformes (Figure 7).

Ratio of similar and dissimilar amino acids is studied for many proteins. A study in this line was done on fibrinopeptides of 34 mammalian species. Out of three chains (α, β and γ) of fibrinogen, the α and β chains (called fibrinopeptide A and fibrinopeptide B) were sequenced for amino acid positions. The data obtained used in phylogeny and that

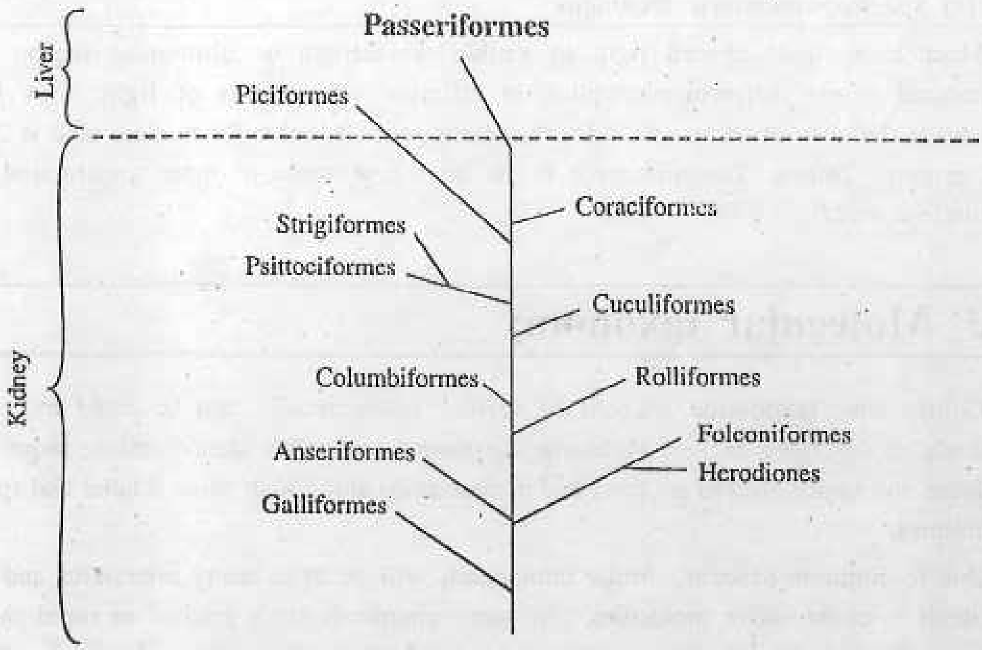


Figure 7. Phylogeny of birds on the basis of sites of synthesis of L-ascorbic acid

has supported the existing phylogeny for those species. There is distinct divergence of canines and bovids from human, monkeys and rabbits.. Similar study on cytochrome C (containing 110 amino acids) has been done on many species and the results perfectly match with established classification.

The essence of chemotaxonomy lies in that every organism synthesizes numerous chemicals on demand of physiological activities. The molecules are product of complex gene action and are ultimately controlled by specificity of genome of a species. The most observable changes are the coloration and communication. Many taxonomists, however, argue to the relative importance of chemotaxonomy than morphotaxonomy

The nucleotide sequence of structural genes determines the sequence of amino acids in a protein. So protein taxonomy is a good tool in species identification. The commonly employed technique is electrophoresis which is not hundred percent accurate and this is discussed latter. Lewontin (1975) pointed that out of 1/3 of all amino acid replacements are detectable by gel electrophoresis..

Gel electrophoresis has contributed valuable data in taxonomy to measure genetic differences among related species and thus helpful in phylogenetic study.

2.3.1 Principles and techniques in electrophoresis

Because proteins have net electric charge, isoelectric point (discussed later) and specific molecular weight, they can be separated from a sample through their differential rates of migration over a gel. Some commonly employed methods are discussed here.

(i) *SDS polyacrylamide electrophoresis*

This methods depends upon the fact that proteins binds the same amount of SDS per gram and binding occurs predominantly at hydrophobic regions. It requires some reference proteins, very little material and is simple. If coupled with silver staining method, it can be used in submicrogram level. SDS or sodium dodecyl sulphate is negatively charged ionic detergent, which binds with protein chain at regular intervals and also denatures it. This unfolds globular proteins (excepting regions with disulphide bonds). The net charge of SDS-protein complex depends upon the length of original protein chain and does not depend on the amino acid sequence. Migration of SDS-protein complex reflects the molecular weight of test protein.

(ii) *Gradient gel electrophoresis*

Proteins differ in their molecular weight and sizes. A suitable gel medium is prepared which allow a gradient of strength that changes from one end of gel to other. This allows initial protein sample at low strength (ie. having large pore size) and their rate of progression is retarded and then arrested. In this way proteins having varying shapes are isolated.

(iii) *Isoelectric focusing (IEF)*

Some amino acid replacement may not alter net charge of a protein (e.g. when amino acid Lysine is replaced by Arginine: both having amino group in side chain). Such amino acids and proteins having both carboxylic and amino acids as side groups (zwitterions) show changes in ionization states of its side groups in response to pH changes. For example, at high pH, only carboxylic and at low pH only amino groups are found to be ionosed.. By trial a pH value can be obtained at which there will be ionization of equal numbers of both positively and negatively charged groups and hence there will not be any net charge. This pH value is isoelectric point for that protein. This is a highly specific and sensitive value of a protein and any minor change in amino acid composition will be detected easily.

This procedure is expensive and is usually combined with other methods. The combinations are standard electrophoresis followed by IEF or SDS, IEF followed by SDS or standard electrophoresis followed by gradient electrophoresis.

(iv) *Two Dimensional Electrophoresis*

This technique is much used in gene technology, detection of many diseases and also contributed to human chromosome mapping by sequencing DNA and protein. The requisites of this method are IEF, a pH gradient (increasing gradually from anode to cathode) and a special buffer called carrier ampholytes. First proteins are separated in a tube gel of polyacrylamide gel followed by electrophoresis perpendicular in a second dimension in a slab gel.

2.3.2 Allozymes and isozymes in taxonomy

These are those different enzymes produced from a single locus. Isozymes (isoenzymes) are enzymes produced by genes at different loci. In practice enzymes of Kreb's cycle and glycolysis are studied and these are stained after electrophoresis. Monomeric allozymes (single protein chain) normally, but not always; gives single band in zymogram. If it is

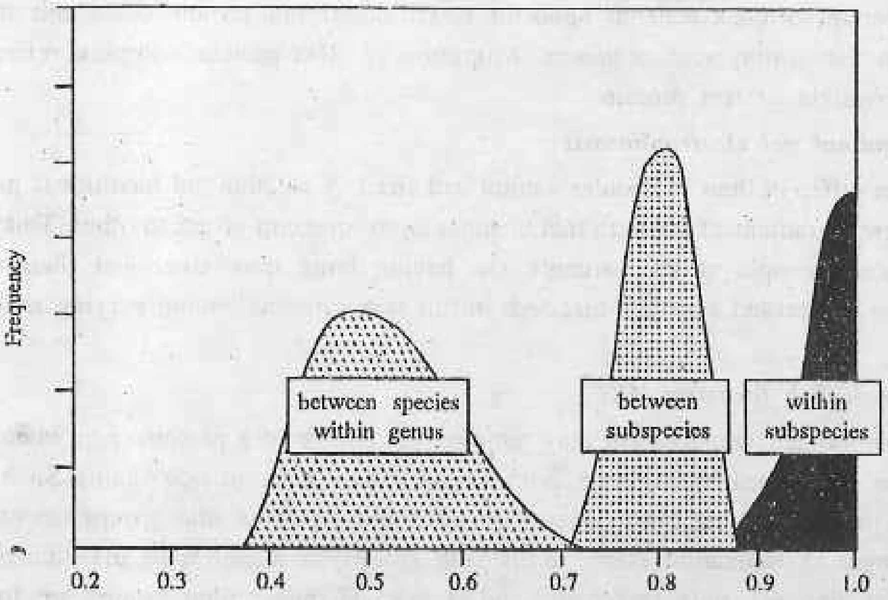


Figure 8. Genetic similarity index based on allozymes at subspecies, species and genus levels

oligomeric, say a dimmer (consisting of two separate protein molecules coded by same gene), then homozygotes give single band and heterozygotes will give three bands (one for two fast moving, one for two slow moving and the third one comprising one of each).

Allozyme study has profound effect on population genetics and taxonomy. Keeping in mind that there are other sources of variations in allozyme mobility, its banding pattern generally correspond to the genotype. The frequencies of different alleles of a polymorphic gene, under stable natural condition, follow Hardy-Weinberg equilibrium. If the samples show different frequencies, we may predict that they belong to separate populations.

Avise (1974) stressed the importance of isozyme studies in systematics and found very high degree of genetic similarity within species and the value is quite low among congeneric species with virtually no overlap between two sets of results (Figure 8).

2.3.3 Protein sequencing

(i) *Selective cutting of protein chains*

Endopeptidases cut protein chain where a particular amino acid or groups of amino acids occur. For example *Staphylococcus aureus* V8 cuts at carboxyl side of glutamyl or glutamyl and aspartyl residues. Some chemicals such as cyanogens bromide cuts proteins at carboxyl side of methionine residues and produces large sub-units of that protein. Trypsin cuts proteins at arginine and lysine residues. Thereafter electrophoresis becomes easier for such smaller digests.

(ii) *Sequencing amino acids and triplet codon*

Since there are twenty different amino acids, therefore each amino acid position can be dealt as a character. Thus there are twenty-one different possible combinations (including one chance for an amino acid to be lost). A change for methionine to tyrosine or opposite requires a change at all three positions in the triplet codon (AUG → UAU). Similarly to change an aspargine to lysine requires only one change at 3rd position in the codon (AAU → AAA). Based on these observation Fitch and Margoliash (1967) proposed that a transition in amino acid sequence should be thought in the light of base changes in triplet codon and calculation to be done on their probability which actually shows the sequence in separation and direction of divergence of taxa.

Nucleotide replacement data are used in taxonomy in two ways: distance based analyses and parsimony analysis. In former a distance matrix is prepared by summing up the total number of nucleotide replacement between a pair of taxa. In parsimony analysis, as shown before, twenty-one different alternatives are treated as character states.. The amino acid serine, however, is treated as two separate characters because its codons are variable.

Remarks : There are some difficulties in the application of data on amino acid sequence in taxonomy. Although the parsimony analysis based on protein sequence done by Penny and Hendy (1985) shows good correlation between tree length and different proteins, the shortest tree was not shortest for all five proteins individually. Thus this method is an approximation to true phylogeny.

An interesting observation by Grahthan et al., 1986 is that for a particular amino acid, organism shows preference for a particular codon (although an amino acid can be coded by any of six combinations). There is so far no explanation to this and probably related to unavailability of specific tRNA. This prefernce may alter to some extent one amino acid to another. However this biasness is not uniform and is quite different in different taxa.

Fitch (1984) advocated that merits of parsimony analysis yields better results done on amino acid replacement data than that of nucleotide replacement data as later increases the number of characters for analysis.

2.3.4 DNA-types, sequencing, principles, use in taxonomy

DNA technology is progressing at a high rate and lots of data on nucleotide sequencing are now available for taxonomic purpose. The various types of DNAs and RNAs studied so far show both potentiality and problems in their use in sequencing.

(i) ***Functional and non-functional nuclear DNA***

The length of eukaryote DNA may be about 100Mbp (megabase pairs, as in Horse-chestnut tree and a nematode) and up to 100,000Mbp in some organisms. The average value ranges from 1000 to 10000 Mbp. However the number of functional genes along with their associated sequences account for only 100Mbp and rest are, therefore, non-functional. It is observed that their haploid genome contains one or few copies of these functional genes. Their number, however, increase by gene duplication.

(ii) ***Repetitive DNA***

Besides functional genes, eukaryote genome contains 25% to 80% of nonsense sequences. Some highly repetitive sequences form satellite DNA. By specific endonuclease, such DNA can be cut and separated elctrophoretically. This method was applied to the phylogeny of whalebone and toothed group and has proved the monophyletic origin of the Order Cetacea.

(iii) ***Mitochondrial DNA (mtDNA)***

Excepting four phyla of Protista and few fungi, all organisms have mitochondria. Again, the mtDNA is circular excepting some alga and species of *Paramecium* where this is probably linear. This DNA may contain 16 to 100 or even 240 kilobasepairs in some higher plants. The rate of mutation of mtDNA is five to ten times more than nuclear DNA(exceptions are echinoderms where both the rates are similar). Thus either mtDNA is showing higher rate of evolution than nuclear DNA or opposite to this. Therefore high rate of change in sequence means the population will be polymorphic for particular nucleotide substitution in the absence of proper time for selection. This fact is useful to draw intraspecific as well as interspecific relationships. Study on nucleotide sequences of mitochondrial rRNA shows that this is far more similar in prokaryotes than eukaryotes.

(iv) *Chloroplast DNA (cpDNA)*

This DNA is circular, about 135000 to 160000bp long and unlike mtDNA is more conservative and is inherited through 'mother'. These features are compared with nuclear DNA and results are utilized to predict their history, such as past hybridization or introgression. This has proved multiple origin of a hybrid *Aegilops triucalis* which contains two distinct types of cpDNA.

(v) *Ribosomal RNA and ribosomal genes*

Ribosomes evolved quite early in organic evolution. It is present in large number in each cell and very much similar in all organisms. It has been proved that there are differences in average rates of nucleotide substitution in different domains of rRNA. Thus each subunit of ribosomes contains some information of divergence in relation to changes in sequence. Some sequences show very little changes so far and these can act as primer (called universal primers) for other organisms to detect changes in rest of the sequences.

(vi) *Transfer RNA*

Transfer RNAs (tRNAs) are universal occurrence in living system and are highly conservative in nature. There are nearly 60 tRNA genes in prokaryotes and up to 8000 in eukaryotes and latter may be due to large tRNA turn over for the demand by cellular activities. The genetic code is almost uniform in living organisms. But this is not the rule for some protistan ciliates. The codes used by mtDNA and cpDNA also varies from nuclear DNA. This aspect probably is helpful in future phylogeny analysis.

(vii) *Prokaryote and viral genome*

Viral genome may be a DNA or RNA and show enormous variation. Whether they had single or multiple origins is yet to be decided. In prokaryotes, the main or nuclear DNA is a closed loop, without histone. The DNA other than this nuclear DNA is called plasmids. The plasmids do not regulate major metabolic activities but one involved in sex has role in antibiotic activities.

(viii) *G+C and A+T ratio*

This ratio varies widely even in major groups of organisms. In prokaryotes the range of variation is 25% to 75% with very little variation in relatives (10% to 15%). This data reflects the constitution of entire genomeand therefore can be used as yardstick in measuring phylogenetic distance between taxa. The principle of this method of measuring the G+C and A+T content is that G+C is more heat stable (by the presence of three hydrogen bonds, A+T has two such bonds). So DNA separation is related to increased absorbance of UV light at 260nm.

(ix) *Restriction site analysis*

Restriction enzymes (endonucleases, such as Bam HI, Hind III etc.) can recognize and cut DNA at specific sites depending upon length and purity of DNA. The sites are fixed for members of a species population and different in unrelated groups.

There are different probes that recognize different sequences and they can be used for each restriction enzyme. Thus a range of combinations of these two will determine presence or absence of restriction sites. This data is used in phylogenetic analysis. In case of large nuclear genome, there is large number of restriction fragments which will show their length polymorphism (Restriction Fragment Length polymorphism, RFLP). In case of RFLP, the observed variants are not due to deletion or insertions but simply due to gain or loss of restriction sites (Shields and Helm-Bychowski, 1988).

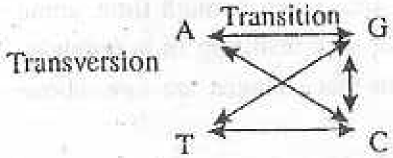
The importance of restriction site analyses is manifold. For example, restriction fragment analysis of nuclear rRNA genes provides evidence of events over far greater time scale than similar study of mtDNA. Latter provides evidence of events during recent past including intraspecific events (such as origin of human race). The procedure is often cost effective (Hillis and Moritz, 1990).

(x) *DNA fingerprinting*

This technique, so far developed, is used in forensic medicine to detect close relation between organisms(human). This involves detection of the length of 'minisatellite DNA' sequences present in genome. Such DNA consists of various lengths of uniformly repetitive DNA in many separate loci. Each such repeat unit has a highly conserved core sequence of about 30bp. A single restriction enzyme with radio-labelled core sequence probe will produce restriction fragments that may contain many minisatellite loci.

(xi) *Rates of transition and transversion*

Through mutation a transition will occur when a purine or pyrimidine base is replaced by the other purine or pyrimidine base.. A tranversion mutation is the replacement of a pyrimidine by a purine base or vice versa. The rate of transition is far more than transversion although there is double chances of transversion mutation than transition mutation. Depending on time scale, it is expected that closely related taxa will show more transition and transversion. Distantly related taxa (with enough time to deviate and evolve through mutation) are expected to show a ratio approximately equal to 1:1 (transition: transversion) (Figure 9).



Transitions : A to G, T to C = 2 numbers

Transversions : A to T, A to C, G to T, G to C = 4 numbers

Figure 9. Possible routes to transition and tranversion

(xii) ***Insertion and deletion***

The differences in two DNA sequences may be by a single base pair or multiple base pairs. In former case, the single base pair difference may be due to addition or deletion during the course of evolution. This event can be treated as single character state and is not a problem in parsimony analysis. But in case of multiple base pairs where the difference is high, there are many events of addition or deletion or both during evolution and they have created divergence in the taxa.

(xiii) ***Secondary structures of DNA and RNA***

Secondary structures of DNA and RNA show that some parts are complementarily double helical in nature while some regions are single (unpaired). The complementary nucleotides do not easily mutate showing their conservativeness while unpaired sequences are prone to alteration. Their mutation rate is high and this may be related to their less functional significance. Therefore these unpaired sequences have less detectable expressions and fail to yield valuable taxonomic data.

(xiv) ***Dealing with fossil DNA***

Available DNA content of fossils is very low than originally it had in living state. This is due to denaturation and oxidation of bases particularly the pyrimidines. Still, the minute quantity that is available can be easily amplified many times and, with the help of suitable probe, their base sequences can be determined. The nature of the preservative in the fossil is an important factor in DNA preservation. For example, Cano et al. (1992) analyzed nearly 1000bp from the DNA of amber preserved Cretaceous stingless honeybee (55 mya*). Similarly Golenberg et al. (1990) successfully analyzed many sequences of magnolia leaves (17 mya). Other studies were on ground sloth (13 000 ya), quagga (relative of horse and ass). However attempts to decipher the sequence of mammoth failed.

Discussion

The achievements on DNA technology are outstanding. Still many aspects are unsolved. Some are summarized here.

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* mya-millions of years ago

(a) Each nucleotide sequence has four possible variants and, given enough time, some positions in homologous chromosomes may alter in a similar way resulting in homoplasy. Therefore parsimony analysis which is based on assumption that changes are rare, above phenomena create problems.

(b) Reversal can well be a problem in parsimony analysis.

(c) If there is more than 75% divergence in two sequences, the information content in the sequences cannot be utilized or assessed. In this case tranversions can be studied as a rare event.

(d) Proportion of transitions decrease as the two taxa are diverging.

(e) DNA of some organisms show strong bias in thir base composition and if such DNA is very rich in A-T content, then more transversions are likely to occur and A to G or T to C transitions will be rare. In such case, transitions will be more reliable and informative for parsimony analysis.

(f) Amino acids are more subjected to selection pressure thereby increasing problem in the analysis of protein coding sequences. So we choose to analysis of third position in the codon. But this third position changes at higher rate.

(g) At present stage, complete sequencing of DNA of any fossil specimen seems impossible particularly due to oxidation and denaturation. This is more true for older fossils.

UNIT 3 ❑ Dimensions of Speciation and Taxonomic Characters

Structure

3.1 Dimensions of speciation-types of lineage changes, production of additional lineage

3.2 Mechanism of speciation in panmictic and apomictic species

3.3 Species concepts-species category, different species concepts, sub-species and other infra-specific categories

3.4 Theories of biological classification, hierarchy of categories

3.5 Taxonomic characters-different kinds, origin of reproductive isolation-biological mechanism of genetic incompatibilities

3.1 Dimensions of speciation

Each member of a deme (a local population) has an equal chance of mating with a partner of opposite sex and this follows Mendelian laws and hence also called Mendelian population by Wright. The gene frequency (or allele frequency) and the gene pool are the two aspects of importance in consideration to evolution of this population. According to Hardy and Weinberg principle the result of random mating (panmixia) among the members will preserve the gene frequency although the genotype frequency may change in the first generation provided that no external influence will act on this population. However, after the first generation, the genotype frequencies will also remain stable, that is at equilibrium.

3.1.1 Factors influencing gene frequency

1. However, Hardy and Weinberg principle is unfit for the population with inbreeding or non-random mating (extreme cases are self fertilization). But ***inbreeding does not alter gene frequencies***. It expresses rare recessive genes (allele) due to increased homozygosity. There is also inbreeding depression when the expressions are deleterious.

2. ***Mutation changes the gene frequency*** of a population through the production of changes in the nucleotides. However Fisher calculated that the chance of losing of the newly mutated gene in just by one generation is 33%. The only alternative way to change the gene frequencies is the frequency of mutation. This rate is, however, not constant.

The approach to mutational equilibrium is very slow and is hardly ever reached. Thus this is not a good cause to change gene frequency.

3. Gene frequency can be altered by the ***differential viability and fertility of the genotypes***. Some are more viable than others and thus selection works on the various genotypes. The number of fertile offspring produced is an index of fitness of a genotype. This selection works at haploid (gametic) or diploid (zygotic) stage when the gene expression affects the survival. A selection in haploids will show no difference between dominant and recessive genes since they show phenotypic expression. The deleterious recessive alleles are expressed and are eliminated in one generation. Thus the selection effect is more rapid and direct on haploids.

4. In cases of reversal of selection a ***recessive allele may be favoured over the dominant***. If the dominant one is lethal, its frequency falls to zero. Therefore the degree of heterozygote expression of deleterious genes determines the effectiveness of selection.

5. Heterosis (or hybrid vigor) is the superiority of heterozygote by way of reproductive fitness over the homozygotes. This condition is called ***overdominance***.

6. Superior heterozygotes with different genotypes show ***polymorphism***. The example is the *HbA/HbS* (sickle cell gene) in men can protect them from malaria than men with *HbS/HbS* or *HbA/HbA*. Industrial melanism is an example of differential selection coefficients in different environments of a widespread population. With change of situation (reduction in pollution) there was reverse evolution, the melanic forms showed reduction in population.

7. Batesian mimicry, Mullerian mimicry and self-sterility in plants are examples of ***frequency dependent selection***.

8. A selection usually tends to be stable and most phenotypes cluster around the optimal phenotype. A selection may be ***directional*** (used by animal and plant breeder to produce better yield) and in evolution extreme phenotypes show adaptation to a changed environment. But in discontinuous environment these selections are ***disruptive*** or ***centrifugal***. According to Red Queen hypothesis, each species faces environmental changes and hence newer selective challenges and fitness. Thus attainment of equilibrium frequency of a mutant gene both mutation frequency and selection coefficients are vital.

9. The presence of ***modifier genes reduces the effects of deleterious genes*** at other loci.

10. Since different populations have different gene frequencies, ***migration will cause receipt of gene flow***. The effect of migration depends on differences in gene frequencies of the two populations and amount of genes taken into by the population. However, migration affects the local evolutionary changes.

11. ***Genetic drift alters the gene frequency,*** particularly if the size of the population is small. Random genetic drift is a non-directional force.

Thus it is evident that there are three directional forces - mutation, selection and migration. The one non-directional is genetic drift. There are some other unnatural events when the gene frequency may change. These are sudden change in environment, rare hybridization event, and unusually favourable mutation. These rare events change the course of evolution to a situation, which is not easily explainable.

Genetic variation and evolution

Drawin was aware of heritable variations but could not explain the underlying mechanism. He even concluded that some variations were better than others, and natural selection favoured former and helped the progeny with better reproductive fitness. Thus useful variations spread while less useful variations Were gradually eliminated from the population.

R. A. Fisher (1930) stated in the Fundamental Theorem of Natural Selection "the rate of increase in fitness of a population at any time is equal to its genetic variance in fitness at that time." Similarly Ayala (1965a, 1968a) working on *Drosophila* has experimentally shown that there is a positive correlation between the rate of evolutionary change and amount of genetic variation. His observation was based on 25 generations under conditions of increased genetic variation. The rate of adaptation to the experimental condition of increased and stiffer natural selection, where the fly had to compete for food and space, was found to be significantly greater.

Genetic variation in loci

H.G.Muller and his students proposed the so called *Classical* hypothesis to state that a typical individual having wild type allele at every loci is said to bear the 'normal', ideal genotype. The individual is heterozygous for a small proportion of the entire genotype by the presence of mutant allele. The mutation pressure introduces the mutant allele in the population and, being deleterious, is later on rejected by the natural selection. However, any mutation that increases reproductive fitness will be preserved by natural selection and will increase its frequency and replaces the original wild type.

The *balanced* hypothesis was proposed by Dobzhansky and his students (1970) as well as E.B.Ford(1971) of Great Britain, They disapprove any 'wild' or 'normal' type and the gene pool is heterozygous at most of the loci. Only a little portion of the genotype is homozygous. That means allelic polymorphism and fitness of an individual depends on the presence of the different allele at different loci and the impact of the environment. Gradually there is a change in frequency of this allele and in kinds of allele at many loci. The deleterious allele rarely appears in homozygous state and these are kept at low frequency by natural selection.

The balanced model has proved its superiority over classical and during last decade allelic variation has been extensively studied. Some of the studies include polymorphism in snails, butterflies, grasshoppers, ladybird beetle and birds. By artificial selection of specific genetic variation has provided us a lot of commercially desired traits in plants and animals.

Rates of mutation and evolution

Considering the total amount of genetic variability present in a natural population, the vast variants arising in each generation will represent only a small fraction of the entire population. Molecular techniques have shown that in sexually reproducing population 50% of the loci are polymorphic and an individual is heterozygous at 5%-20% loci only. The number of variants produced, hence, would be 25%-10% total structural genes. Therefore mutation rate and evolutionary rate are not likely to be closely correlated.

Genetic variability and production of lineage

The genetic variability in a gene pool are acted upon by natural selection and finally produce or accumulate useful and heritable varieties of changes in the population. The paleontological method to classify evolutionary rates into those commonly found (horotely) into slower rate (bradytely) and faster rate (tachytely). Such heritable changes may be minute (*microevolution*) or large and distinctly visible (*macroevolution*).

The three factors responsible for different rates of evolution are :

(a) The size, genetic variability and pattern of distribution of a population. The fragmented populations show faster evolution than a homogeneous and interconnected population (Wright).

(b) Developmental constraints can limit or dictate the structures and functions organism can achieve. Evolution never stops by presence of constraints, only latter open up newer paths.

(c) The direction and intensity of selection were different during different major geological events in the past.

3.1.2 Theories on differential rates of evolution

(a) Punctuated equilibrium theory :

Punctuated equilibrium theory by Gould and Stanley is based on the studies of fossils. It is proposed that fossils show rapid macroevolutionary events after long intervals of microevolutionary stasis or equilibrium, punctuated by rapid macroevolutionary periods during which new taxa arise through entirely new causes and mechanisms.

(b) theory of macromutational events :

The theory of macromutational events was proposed by Goldschmidt (1930s, 1940s). According to this view, each macroevolutionary change is a macromutational event. Such mutation was enough to produce large developmental effects in organisms, which entered new adaptive zones.

But any such serious mutation that is able to produce a new species would probably be non-viable. Hence proponents of punctuated equilibrium have partly rejected the idea that i) significant developmental effects can be produced by regulatory mutations and ii) there may be occurrence of "founding accidents" or "bottle neck"; these two are sources of macroevolutionary mechanisms.

Microevolution

Studies on invertebrate fossils by Rowe and Fenton provided examples, which show slowly, and gradually a species evolved from existing species with very little changes in intermediate forms (or variants). These minute changes accumulated and ultimately produced 'living fossils' like *Latimeria* and *Neopilina*.

The examples of microevolution by Rowe distinguished several lines of descent in *Micraster*, a sea urchin. The changes that took place in a static environment have forced the transformation of *Micraster corbovis* to *Micraster coranguinum*. The brachiopod *Spirifer* found in the Devonian strata suffered rhythmic fluctuation of environment. But the evolutionary changes found in these organisms were not correlated with the environmental changes.

Microevolution takes quite longer time and the process is very slow. Successive forms are represented in successive strata in a paleontological series. Hence this is also named as 'successional evolution'. A parent population may break up into two or more subpopulation and each division undergoes its own history of evolution. The interbreeding population will spread its acquired genetic mutation and this subpopulation is tested by natural selection.

Microevolution is a gradual change in an interbreeding population through gene mutation. These mutations are either spontaneous or result from environmental pressure. Goldschmidt identified macroevolution for the origin of subspecies and race while macroevolution for the origin of species and genus.

Macroevolution

The parent population splits into several species population in a shorter period due to some urgent situations prevailing in nature and is also explained as *adaptive radiation*. Simpson gave the name *quantum evolution* to this process. It involves allometric changes with increase in size and weight in response to environmental situation among members of different populations. The examples are in the evolution of horse, elephant and others. According to Savage (1969) the reptiles also show macroevolution. The drastic and diverse conditions in nature help in divergence of a population and the time required is mostly short. Therefore the rate of changes in environment is the determining factor whether an evolution should be micro-or macro-in nature. The fossil records suggest that during the Silurian period no major taxa underwent rapid evolutionary changes because it was a period of almost uniform conditions. But most modern phyla evolved during the Cambrian. Similarly many groups radiated in the Devonian. Both plants and animals again radiated in the Jurassic and Cretaceous. Above changes are correlated with the six mass extinctions.

Our recent time is again a period of mass extinction, which is caused by the extensive modification of habitat by human species. The destruction of tropical rain forest, which harbours more species than any other habitat, is most threatening. Biologists predict that one million species are going to be lost within the next century and it means that the present rate of extinction will be unparallel in the history of life on the earth. Another important aspect of present extinction is that it will not see any new adaptive radiation by the interference of human itself.

Mechanism of macroevolution

The pattern of evolution of various groups show that there was far rapid evolution in some groups than other groups with slower rates. The causes so far known are natural selection and unknown unique historical phenomena. Adaptive radiations in many groups were due to changes in geo-climate and related newer ecology. Many structures were remodelled and newly developed to adjust with newer environment. The result is also decline or even extinction of many groups that failed in their speed of acquisition of structures or adjustment needed to survive. The time was important criterion to solve their problems within short span in relation to geological events. Dispersal played an important role where new comers to a new zone responded quickly to adjust with the newer habitat.

The development of trunk in modern elephants is another example of adaptive radiation. The evidences show that the ancestral fossil Mastodon, *Gomphotherium* of mid-Miocene of North America had short tusks and trunk. Gradually there were reductions in the size of lower tusks and lower jaw with a consequent elongation of trunk. This was helpful for this large grazer who requires more food and hold more amount of vegetation at one time. The second line of radiation for the same purpose was the increase in the width of mouth instead of development of trunk was going on in white rhinoceros.

Isolation by physical means is a great example of macroevolution by radiation. South America lost its continuity with the North America and mammals on either continents evolved separately. Thereafter (about two to three million years before), the continents were connected by a narrow land bridge, the Panamanian land bridge, and massive interchanges started. Now the separated oceanic forms evolved in their own way and presently there are three hundred and ten pairs of species on either side of the bridge, which undoubtedly evolved from the one ancestral species. South America experienced radiation of monkeys and histricomorph rodents (guineapigs and related forms). Both of these groups came from north or from the nearer continent (Africa). There was also radiation and consequent diversity in marsupial fauna in South America.

Paleontologists believe that macroevolution resulted from continental drift and this is also an important cause of mass extinction and adaptive radiation. It is easy to understand that the single mass of land (Pangea) of late Paleozoic was the source of origin of most of the land animals. Later fragmentation and separation of the land masses acted as a barrier and forced separate evolution. Through dispersal newer forms entered the changed habitats.

The phylogeny of the different taxa reveals that, soon after appearance of any major phylum it undergoes evolution of various classes and the latter underwent modifications to produce various families. This divergence may be at different rates along different lines.

The incomplete fossil record provide little clue to how the new phyla appear suddenly. One explanation seems to be speciation at peripheral zones where members are subjected to a situation different from the core area of the parental species. The core forms gradually become rare and restricted as local forms. Another explanation is that the sudden and changing environment after mass extinction forced development of newer characters among members of parental species and they undergo new stiffer pressure of natural selection. Only few survive those quick changes while most face extinction. Thus evolution goes on along any undetermined ways and is 'opportunistic in nature'.

Evolutionary lineages

Animal classification today is based on critical analysis of evolution; still many places in animal hierarchy are controversial or unsolved. Taxonomists usually group together taxa with common evolutionary history. The work is toughest one and sometimes opinions differ in this regard so that different phylogenetic schemes are not uncommon.

The members of *monophyletic* taxa are descended from one common ancestor. If the members of a taxon originate from more than one ancestor, they will be called *polyphyletic*. According to different views the monophyly can be achieved in three ways.

(i) The members are said to be *strictly monophyletic* if they descend from single parent or at least from same species or population (Fig. 2a and 2b).

(ii) The ancestor belonged to a different taxon but later on undergone much changes and radiation and ultimately produced several lineages all of which belong to taxa different from ancestral taxon.

(iii) The ancestor and its monophyletically evolved taxa belonged to a single higher taxon (Figure 10).

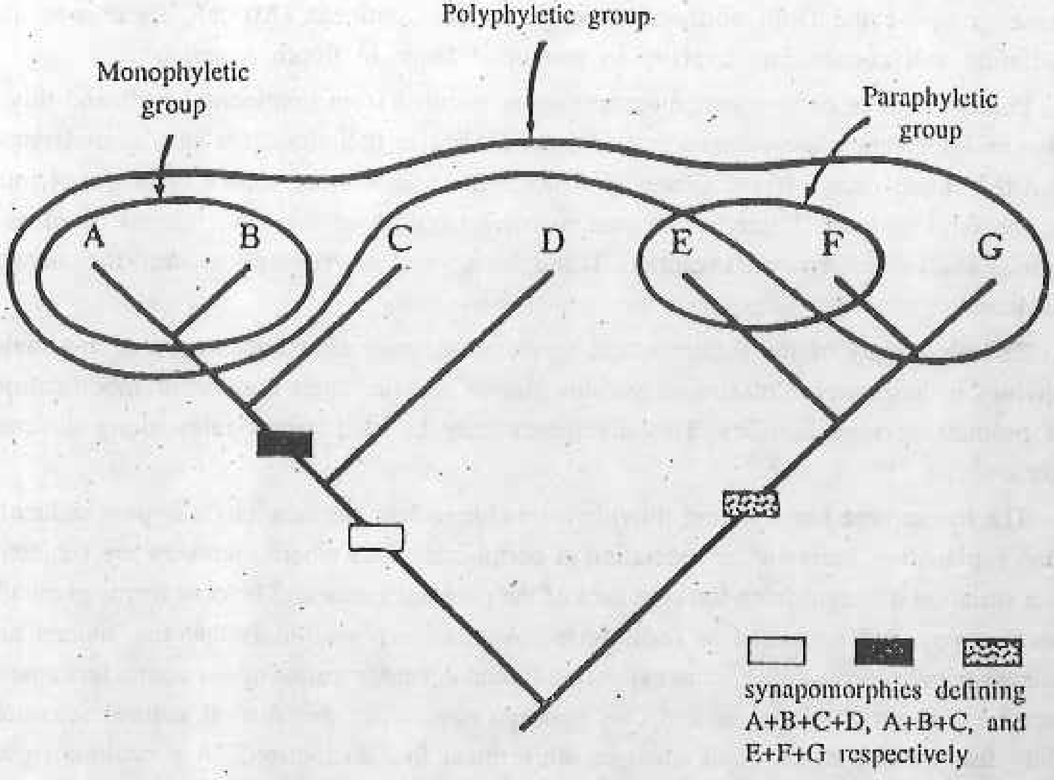


Figure 10. Diagrammatic representation of monophyletic, paraphyletic and polyphyletic groups

Simpson defined monophyly as the derivation of a taxon through one or more lineages from one immediately ancestral taxon of the same or lower rank. For example the derivation of several genera from one immediate ancestral genus or species.

Relationship between evolutionary changes, additional lineage and persistence

A lineage shows character changes upon passage of time as also branching to produce daughter lineages. Hence Rensch (1954) proposed two terms to explain this phenomenon:

Anagenesis : It is any kind of evolutionary change (advance type or not). The changes produce some novel characters than that of their ancestor and taxa with such characters are grouped together to a new *grade*. This grade may be monophyletic or polyphyletic (example is the independent origin of warm-blooded nature in birds and mammals).

Cladogenesis : It is the splitting or branching of a lineage. Here clades are the branches of a lineage that has undergone splitting and in broader sense, are monophyletic.

Stasigenesis : It is the phenomena in which a lineage does not split or undergo so much of changes in course of time hence preserve parental characters (Huxley) (Figure 11).

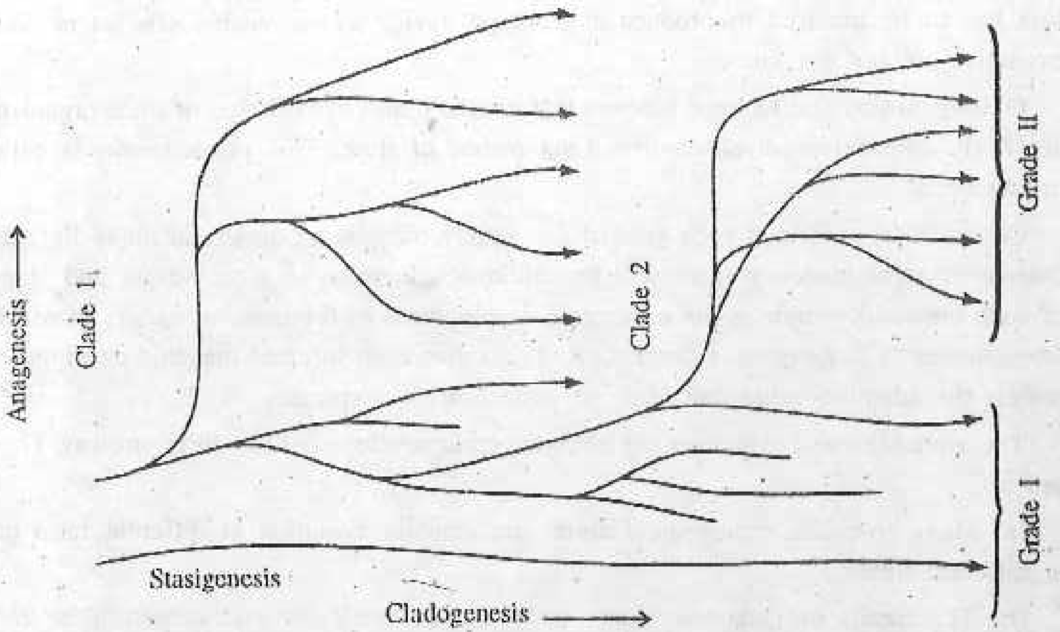


Figure 11. Different lineages showing anagenesis, cladogenesis and stasigenesis

3.1.3 Theories on the production of discontinuous lineages

A search for the ancestor of any two phyla reveals that the branches or lineages that lead to those phyla are well separated when they first appeared in fossils.

The co-adapted characters, according to Darwin, are those characters, which are grouped together into one and, like lineage group, move as a whole group. However, evolution of numerous harmoniously coadapted characters is probably impossible.

A. Saltation concept :

The set of co-adapted characters is unique for a group and if it splits into two or more lineages, then each will develop its own set of novel co-adapted characters at a single jump (***saltation***). This means that there will be no intermediates. Schindewolf (1950) explained the sudden appearance of many new lineages as fossils based on this concept.

Milvart (1871) supported saltation concept and refused natural selection. Through the emergence of Mendalian theory of heredity, the mutation was believed to be the cause of the sudden appearance of new characters and this again believed to support saltation concept.

Goldschmidt supported the large mutations are the causes of appearances of monstrosities which have wide phenotypic differences from ancestral forms. But nearly cent percent loss has to be incurred to produce a genotype having newer visible characters. Such examples are not yet known.

Orthogenesis : Due to some inherent features the trends of evolution of some organisms are fairly constant in direction over long period of time. This phenomenon is called orthogenesis.

Cope (1896) explained such gradual and steady increase in organs in many lineages. Due to inherent tendency there will be continuous increase in size, weight and length of such organs. Example is the orthogenic development of the massive antlers of extinct *Megaloceros* (a large corvine deer). Lull (1922), however, inferred that this development lowers the adaptive value and leads to extinction of a species.

The available fossil evidences explain orthogenic development in a different way. These are :

(a) Many so-called orthogenic features are actually evolution at different rates and at different times.

(b) The trends are adaptive; large body evaded predators and helped more food collection. The antlers were probably used not in fighting and had a role in courtship displays and thus were a better selection and reproductive fitness.

(c) Many lineages exhibited long term trends and increase in body size was normal.

(d) Gould (1973) showed that increase in body size and antler had a positive allometric relation.

B. Concept of adaptive peaks :

Saltation concept was proved to be quite unfit to explain the above trend. The present concept is that adaptive characters are favoured and push better adaptive species to further expansion through fitness. Such adaptive characters are novel and hence have higher adaptive value since their appearance in a population and their gradual refinement up to final stage to be established as a characteristic feature for a higher taxon. This was the essence of the concept of 'adaptive peaks' of Sewall Wright and explains how a population shows transformation of some members without intermediates. Simpson (1944, 1953) explained that members of a population enters completely different ecosystem through dispersal, barrier and other factors. These isolated areas are so much separated and so much different from the home of the parental population that each set requires different sorts of adaptations. The vastness of differences put pressure or adaptive threshold and is the prime driving force for the development of newer characters. Each such new zone may have more than one sub-zones. Simpson termed this as 'adaptive zone', which consists of a taxon together with its environmental characteristics.

Mayr mentioned that due to peculiar environment at periphery the members inhabiting such zones undergo peculiar specializations and evolutionary adjustments (= post adaptation) and gradually evolve into separate lineages. Many of their adaptations are beneficial to the neighbouring zone. These pre-adaptations help the new lineages to flourish in the new zone through better utilization. The new community may suffer huge loss since the new environment possesses unknown threats. Such a population of reducing size may undergo genetic drift and acquire new genotype to overcome the low frequency that might happened through natural selection. However extinction is not uncommon among these forwarding lineages during the episode. The new habitat was unoccupied by same species and there will be no intraspecific competition for the food such new phenomena lead to anagenesis followed by post adaptations and then extensive cladogenesis.

Examples of adaptive radiation and production of additional lineages are well studied in cases like Darwin's finches, Hawaiian honeycreepers, snails along coast of Southern California and others.

Amadon (1950) studied the generic evolution in Hawaiian honeycreepers. The islands provided isolation and subsequent occasional inter-island migration and thus initial allopatry and later sympatry many times for several species. In this family of birds (Drepanididae), the structure of bill and feeding mechanism were important factors determining their radiation; there were food preferences among the members or exploitation of available food types. Bock (1970) explained that initial geographic isolation and obligatory reproductive isolation were responsible for the differences with parental population. This was followed by character displacement which occurred after migration and becoming sympatric. The character displacement is the measurable phenotypic differences in relation to resource partitioning. In Galapagos finches the species coexisting same island show greater differences in size of bill than where these species occur on separate islands.

The Drepanididae has two subfamilies, the Drepanidinae and Psittirostrinae. Latter evolved from former and are far rich in species diversity. The most primitive genus of

Psittirostrinae is *Loxops*, which probably evolved from some early Drepanidinae and radiated into five species. The four of these remained congeneric while the fifth, with many distinctive features, became a new genus *Hemignathus*. The *Hemignathus* radiated into three species with which it forms a rather distinctive adaptive group. *H. lucidus* gave rise to a fourth species so distinct so as to form a separate monotypic genus, the *Pseudonestor xanthrophrys*. Latter radiated to give rise to six living species forming a compact group of their own under generic name *Psittirostra*.

Types of lineage production in short, therefore, are:

a. It is known that numerous aspects of biospace act on a population and force the production of lineages. It may so happen that the functional biospace may undergo division, generally two, or more sub-zones, each with some characteristic adaptive threshold. During anagenesis, a lineage may cross or overcome new adaptive challenges and enter different sub-zones or biospaces. The novel characters that develop in these advancing lineages are peculiar to this group and flow in its descendents.

b. A second pattern may not involve biospace partitioning. Here morphologically distinctive groups may arise due to inherited qualities present in the stem lineage. The stem lineages are quite different from their sister lineages.

c. Cluster of species may show morphological distinctiveness due to extinction of intermediate forms. Thus pattern of extinction may be used as yardstick to develop taxonomic classification.

d. The origin of a new family may be similar to that of the origin of genera. But the differences lie in the degree of variation achieved. This is possible when anagenesis goes on for for a longer period to establish those large differences.

e. Any new evolutionary pathway will follow a new adaptive mode and are sufficiently successful to produce offsprings, which are better adapted through selection. These, of course, create competition among sister lineages and result in extinction of some lineages. The successful ones may acquire fitness through preadaption whose required genetic endowments come from ancestral species.

3.2 Mechanism of speciation in panmictic and apomictic species

The definition of species given by several authors in different times show a change according to the new thoughts and critical examinations through experiments and analysis.

The basic criteria of a species are that it has its own gene pool shared by its members and adjusted to a given environment. The other attributes are the reproductive and ecological separation from any other species and it has own isolating mechanisms.

Earlier in history, Darwin considered a species, as permanent and distinctive variety and each species earlier existed as variety. The term variety was not well explained then and, although races and subspecies are taken as 'incipient species', not all of them will finally become a true species. Only few of these incipient species will show divergence in their genetic combination from parent population and will go on further speciation.

The ultimate production of a species therefore requires genetic differences. This may arise gradually through transformation of geography of distribution and this is also known as *allopatric speciation.* Some authors believe that geographic isolation is not a must for speciation.

The members of a population belonging to one geographical area may face territorial differences (sub-zones). The biotic and abiotic differences of these sub-zones produce initially minor variations. The result is the production of many incipient species within the parent population and selection pushes a few to the status of a new species.

A.R.Wallace (1889) believed that due to differential adaptability among hybrids, the natural selection would favour those that show better adaptations to the prevailing conditions. This separation of the weaker from better forms will create a sort of reproductive barrier. This is a selection for sexual isolation that results from strong adaptations to specific environment by most races and species. Dobzhansky and some other authors supported this view. However a cross between two similarly strongly adapted populations will produce a genotype which i) will be totally different from parent population; ii) obviously will not match the parental environment and hence bound to be disadvantageous. Such hybrids are naturally rejected through selection.

3.2.1 Some experiments and inferences

1. Wasserman and Koepfer showed that allopatric species show no mating barrier on *Drosophila arizonensis* and *D. majavensis*. The sympatric species mated rarely (14/377) while allopatric species mated more frequently (119/473). However the F_1 hybrids were all sterile in both cases.

2. John A. Moore found 29 separate allopatric populations of leopard frog extending from North America (Quebec) to Mexico. They are distinctive populations but produce normal offsprings by cross breeding among adjacent populations. The rate of production of viable offsprings decreases with increase in distance between the populations.

3. Sexual selection is strong in sympatric population. Phelan and Baker observed that there is more scent emitting glands in male of sympatric species inhabiting same host plant than species on different host plants (allopatric).

3.2.2 Different types of speciation in panmictic species

Panmictic or sexually reproducing organisms produce zygotes with diverse genotypic combinations obtained during meiosis and gamete production. If there is heterozygosity for *n* number of genes, a single parent will produce 2*n* genetically different zygotes. So two such parents heterozygous for *n* number of different genes will produce 4*n* genetically different zygotes. Hence Wright proposed that there is unimaginable potentiality in sexually reproducing organisms and what we observe is actually a very small fraction of the same.

In panmictic species, speciation may occur in three ways.

A. Allopatric or geographic speciation

This is the most widely accepted mode of speciation and is almost exclusive for animals. It is a gradual and slow process by which some form of barrier develops to separate a population.

Among many examples, the historical one is a Darwin's finch on Galapagos Islands, which probably originated from a single South American mainland stem species. The fourteen species today are totally distinct from each other. This would have not been possible if all the island masses were a single one. That is what happened to Cocos Island and a single species inhabits there still today without any speciation.

Some of the important factors in allopatric speciation are the type of species, time necessary for speciation, inability to cross a barrier and the size of the geographical area concerned. What is a barrier to a fresh water inhabitant or a terrestrial form may not be the same for some other forms of animals. This is depicted in the figure 12.

Similarly the population in mountain lakes is isolated and shows regional diversity. In this way a single population undergoes fragmentation. *Rana pipiens*, through this process, produced several species today.

Geographic or ecological isolation by some barrier separates the parent population. Now given enough time, the two populations will grow separately and in the long run, there will be much genetic divergence between them. If there is a partial merger in ecosystem (i.e. partial barrier breakdown), the two separate populations will quickly adapt and evolve mechanisms for reproductive isolation. When this isolation is complete, there will be no gene flow between them and a firm species is evolved in this way.

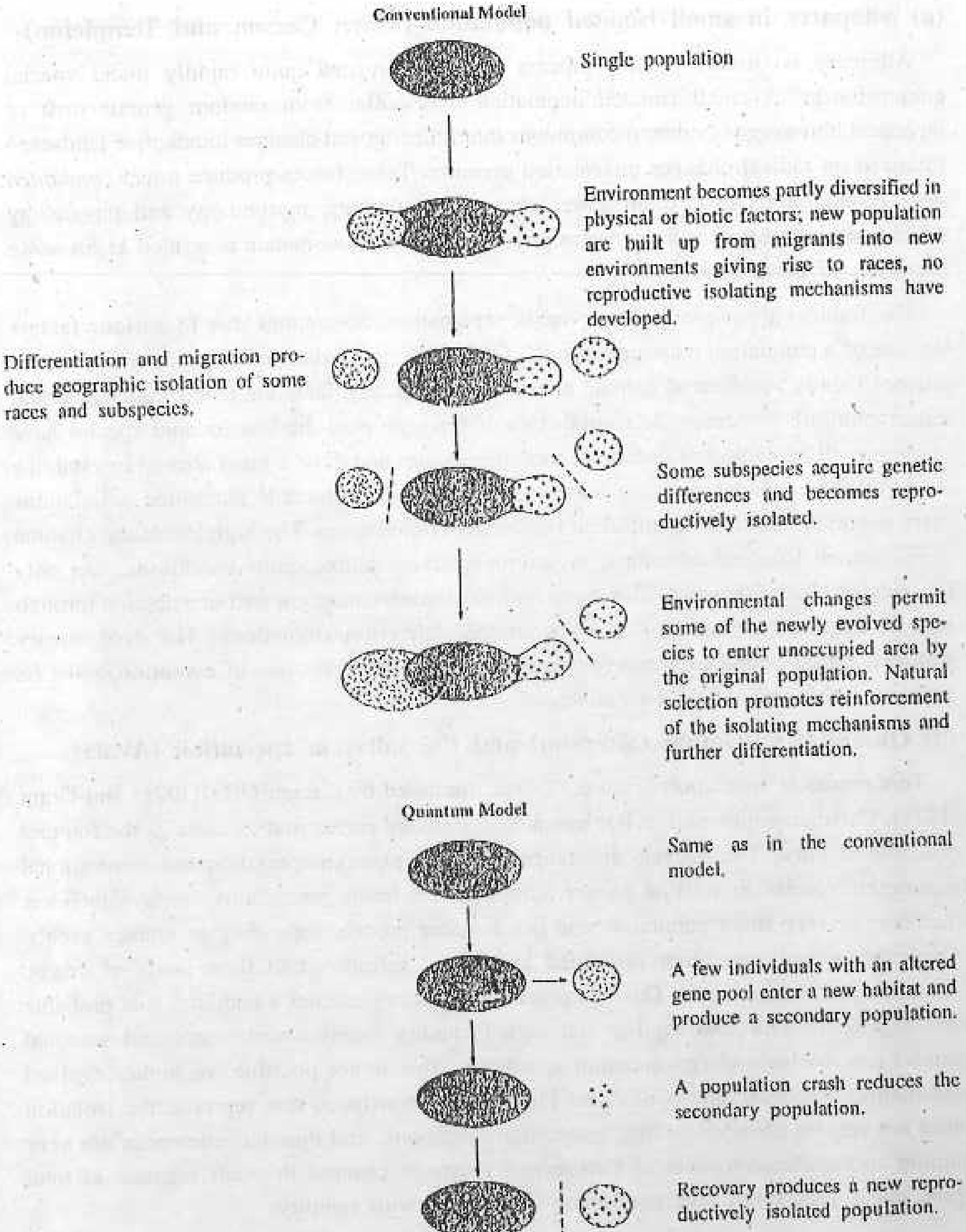


Figure 12. Conventional and quantum models to explain origin of a new species

(a) Allopatry in small isolated population (Mayr, Carson and Templeton)

Allopatry is usually a slow process but may proceed quite rapidly under special circumstances. A small isolated population may suffer from random genetic drift or increased homozygosity due to continuous interbreeding and changes in adaptive landscape followed by radical changes in selection pressure. These forces produce novel *coadapted gene combinations* to develop newer changes in ethology, morphology and physiology which are quite different from parent population. This phenomenon is termed as *founding accidents* or *bottlenecks*.

The founder principle of Mayr needs explanation. Sometimes due to various factors the size of a population may remain small for several generations even this may sometimes reduce. This is an effect of genetic drift and consequent effects on gene frequencies (and thus evolution). Whatever the combination of the gene pool the few founder species have in them, will be subjected to test by natural selection and have a good chance to establish As a result of founder event (= bottleneck effects). It is probable that some populations carry genotypes sufficiently different from parent populations. The high incidence of some genes, which have no advantage in heterozygous or homozygous conditions, can only be explained by bottlenecks. This event nullifies the advantages of earlier selection through loss of favourable mutations and encourages deleterious mutations. The evolutionary pathway, hence bound to change in new direction, which, by law of evolution, must be adaptive, otherwise would be extinct.

(b) Quantum speciation (Simpson) and the saltation speciation (Ayala)

This model of speciation (Figure 12) was discussed by Carson (1973,1975) and Grant (1971). Carson mentioned it as bottlenecks as discussed earlier and its same as the founder principle of Mayr. The relevant differences between quantum speciation and conventional geographic speciation are that former is rapid, takes fewer generations, starts with fewer members or very small population and is a budding process depending on chance events. The conventional speciation is guided by natural selection and there may be drastic reduction in the population. This is a process of splitting and not a budding. It is probable that organisms with low vagility and high fecundity (many invertebrates and seasonal plants) are able to undergo quantum speciation. This is not possible for higher evolved organisms. The observations of Ayala (1975a) also concluded that reproductive isolation does not require changes in large proportion of genome and thus the inferences are very similar to the closed system of Carson that indicated changes in small segment of total gene pool. This small part may easily reorganize with rapidity.

Carson explained that gene pool of each species has two systems- open and closed types. In open system, the genes undergo free recombination during meiosis and resultant offspring are subjected to natural selection. Therefore there are different gene frequencies and offspring face different environments to produce races or subspecies.

In closed system, the 'super genes' or blocks of gene loci of a species are transferred as a block to offspring. So any change (mutation) or substitution of a new allele will reduce the fitness of the offspring drastically. Carson, therefore, explained that in such a closed system, there is an accidental 'genetic revolution' by which population outbreak takes place followed by a crash. The survivors of this crash have sufficient genetic difference from parent population and slowly increase in number. Carson applied this concept in the speciation of *Drosophila* on Hawaiian Islands. The few founder species (5 in number) from the oldest island (age about 5.6 million years) moved to Oahu Island, which at present has 29 species. There was an interchange of species between Oahu and Maui. The Maui complex became significantly rich in species diversity, which contributed to speciation in Hawaii Island (with present 26 species). Inter-island migration of very few species was also observed and such species have developed formidable reproductive isolation among parental population. The tectonic plate moved the islands formed at hot spot (Hawaii) in a northwest direction until they fragmented and submerged.

In opposition to the concept of bottlenecks, Barton and Charlesworth suggested that speciation caused by single founder event couldn't produce immediately significant change in an isolated population. This is because gene frequency will be altered by genetic drift through many generations. Moreover, the effect of isolation, environmental differences and continuous changes in genotype- are all associated with impact of population bottlenecks. Bryant *et al.* observed increase, instead of any decrease, in phenotypic variation.

Rice and Hostert claim that during genetic differences between populations divergent selection takes place. When such populations undergo dispersal, reproductive barrier develops as a secondary attribute.

(c) Species-specific mutation concept (Goldschmidt for animals and Lamprecht and others for plants).

This concept has not gained support because there was no experimental explanation. The semi-fertile interspecific hybrids of *Drosophila pseudoobscure* and *persimilis* (Dobzhansky (1941) and *Phaseolus mutiflorus* and *vulgaris* (Walls and York, 1957) are reproductively isolated due to presence of genetic differences in several gene loci and no 'species specific mutation' was recognized.

It appears that speciation may occur in different ways, some with rapidity while some at a slower rate. Results of barrier breakdown are the production of viable and fertile hybrids which are particularly common in plants than in animals. This is termed as *zone of hybridization* or *hybrid swarms* and the population has a genotype and phenotype different form the parental population.

When such hybrids are intermediate to a different species, they help to adapt the forthcoming species to its ecological range. Such phenomenon is called *introgressive hybridization* (Anderson)

Hybrid sterility acts as a common barrier in animals but not in plants. In plants polyploidy in a normally vegetative propagated plant ensures production of fertile gametes. Studies shown that half of all angiosperms and most of pterydophytes are polyploid of one or another type and allopolyploid are most common event.

B. Parapatric (Bush, 1975) or stasispatric (White, 1973) speciation

In parapatric model of speciation, there is no geographic barrier and the members belong to a continuous population. It is a rapid process like quantum speciation involving fewer members. But, unlike quantum speciation, the reproductive isolation takes place entirely by natural selection.

Murray (1972) provided evidence in support of this model in the origin of land snails *Partula* on Moorea Island near Tahiti. The total eleven species of *Partula* fall into two functional groups; species of one group while behave as distinct species in one locality, they, however, interbreed freely at other locality only 200 meter away. No geographical difference is observed in these two localities.

White (1968, 1978) observed differences in chromosome configuration in morabine (sedentary wingless) grasshoppers of Australia and suggested this shift in chromosomal arrangement initiated the task of reproductive isolation. The process spread to form a narrow zone of hybrid. But a genetic drift in a small population becomes necessary to increase the lowered fertility gained through chromosomal mutation.

Both of the above evidences lack proper genetic data and it is not clear how these evidences differ from quantum speciation. Thus parapatric speciation is an obsolete concept.

C. Sympatric speciation (Mayr)

Mayr proposed that a population undergoes dispersal and acquire reproductive isolation. Various authors supported this concept for many years. The term *disruptive selection* or *centrifugal selection* was applied to this concept. In a disruptive selection there are members with phenotypic differences at two extremes of expression while intermediate forms are abolished and both belonged to same population. It happens when members of a population are subjected to divergent or oscillating changes of environment and the various genotypes of its members are most suited to such changing situations. Such events may establish genetic differences in a population. Bush accepted that this type of selection might be possible for few specific kinds of organisms (parasites). A female parasite upon entering a new host may undergo sequential events to speciate to acquire new adaptations to establish in the host. There is, therefore, every chance to decline in population as well as the female is producing acquired genetic variations to offspring. Migration followed by natural selection and final equilibrium between the environments of host and the parasite are essential phenomena for the parasite. These and some other unexplained areas put questions on distinction between quantum and sympatric speciation in parasites.

Bush and others proposed that within single geographical habitat different groups of insects undergo speciation by adapting to different kinds of host plants as food source.

According to Mather and Thoday disruptive selection and increase in genetic variability leads to polymorphism and this has been shown in *Biston betularia* and polymorphism and mimicry in *Papilio dardanus*. But Mayr (1963) questioned whether it is possible to maintain divergent condition in a single locality for a long period necessary for speciation.

In plants, sympatric speciation is commonly achieved by polyploidy within a single geographic locality. Close interbreeding is unusual among animals (with few exception as parasitic hymenoptera). In this insect brother and sister emerging from same host mate and Askew (1968) suggested this type of mating is responsible for high species diversity in this group. However reproductive isolation between closely related species cannot be achieved by genetic difference at a single locus, rather several loci need to be changed. Therefore there must be strengthening of barrier between gene flow and the process is stepwise, not rapid.

3.2.3 Speciation in apomictic species

Most of the apomictic plants originated initially and hybrids and thereafter became stabilized. These, by definition of species, are difficult to classify and are not recognized by taxonomists. These plants fall into two categories. In the first category the descendents of the sexually reproducing plants secondarily lost their sexuality including formation of gametes or zygotes. In course of time their polyploid nature is stabilized and no further increase or decrease in chromosomal number takes place excepting rare mutations to produce variants. New apomictic plants are further produced from sexual species. Those of the second category (e.g. *Rubens, Poa* etc.) also cannot produce variants. These are facultative apomictic producing seeds both asexually and sexually. They cannot show new adaptive characters but exist indefinitely. This conclusion is drawn from their distribution and being very common in nature.

Apomixis or parthenogenesis in higher plants is an adaptation to avoid hybrid sterility. Such plants form a complex of many sexual forms, which are quite different from each other, and species recognition among them is unwanted.

In animals, thelytoky (production of eggs without fertilization) is not uncommon in some animals belonging to different phyla. Crustacea (*Artemia*), Coleoptera (weevil), Lepidoptera (moths) even in fish (Schultz 1969, Uzzell 1970), lizard (Darevsky 1966). Complete sexuality or obligate apomixis is characteristic in these forms. But facultative apomixes is not known in animals. There is a tendency for any species to reach an *evolutionary dead end* and probably the number is one out of every 1000 species group. And apomixis in animals appears to be recent in origin.

Lower organisms like bacteria, blue-green algae and others continue genetic recombination by non-sexual methods, such as transduction (transfer of one or some genes by infective non-lethal virus from one bacterium to another. Transduction is easier in closely related strains. However transduction in distantly related strains is not uncommon. Hence it seems that evolution in the prokaryotes took place through diversifying selection and less stress on reproductive isolation. Similar is the situation in fungi imperfecti, many ciliates and sarcodines. Thus the difference between transduction and sexual reproduction is that in former, there is no participation of two full sets of genome obtained from different parents. The new generation of bacteria, after transduction, will not express expected characters of both parents, excepting those few contained in genes came into them. Such events may occur between wide taxonomically distant prokaryotes so that resultant form cannot be placed into any perfect category. That is why Mandel (1969) defined it, as "a bacterial species is a type culture and those cultures resembling it". This definition is far easier and perhaps better.

The evolution of apomictic species of plants is well illustrated by Babcock and Stebbins (1938) in figure 13.

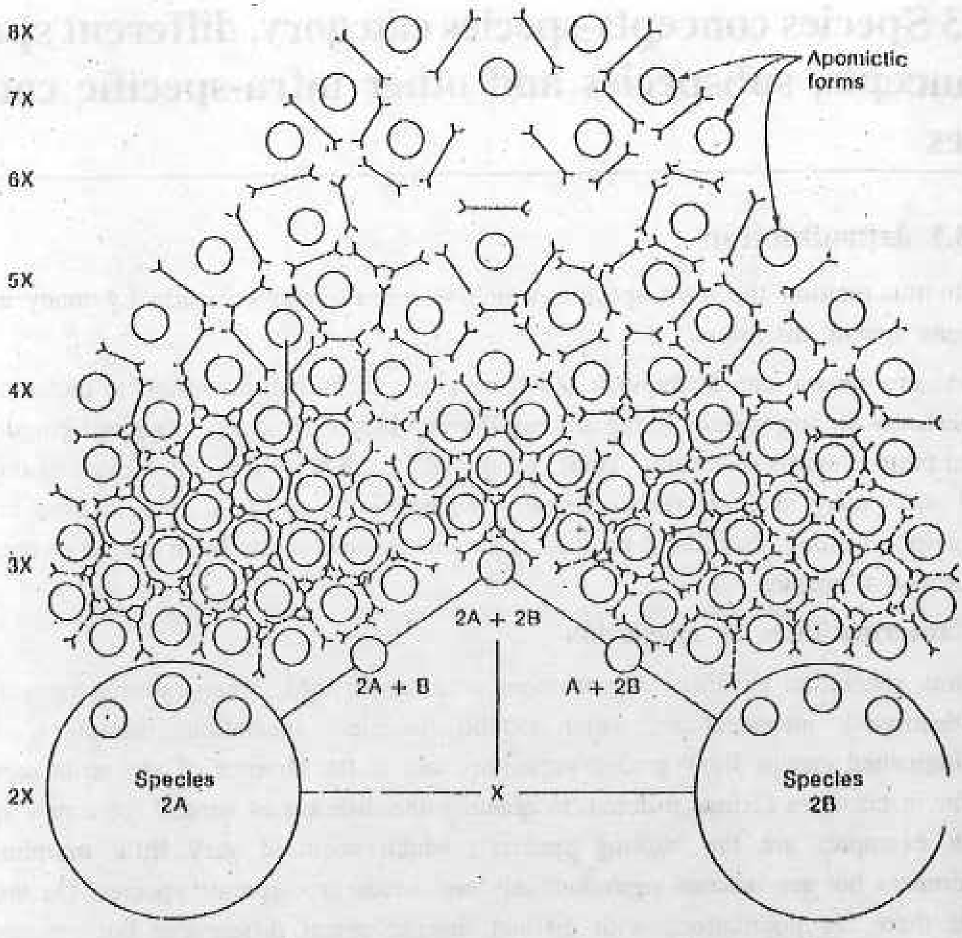


Figure 13. Chromosomal arrangements in an apomictic complex

Explanation to figure 13 :

There are three sets of offspring obtained from two different sexually reproducing organisms. Since these all are sexually infertile, no genetic exchange is possible, which is shown by heavy border I——I. Facultative sexuality may occur among some individuals there the barriers are broken (I——I) thereby producing offspring with higher chromosome number (products of gametes with unreduced chromosome number). In this way higher levels of polyploidy is produced and these agamic complexes have vast array of recombination of characters, but they cannot produce distinctively new characters.

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

3.3.1 Introduction

In this section the term species, which was dealt with critically by many authors, needs special attention.

As any animal can distinguish self from non-self, human also tried to understand the differences among various living and non-living objects. However in animal kingdom any local fauna consists of several "kinds" of animals. Each such kind, upon close examination will show many features which are very much specific to them, such as their breeding behaviour, nesting, food habit ecological parameters and so on. Such a kind of organisms is termed a species.

(a) Intermediates in speciation

Any speciation produces a continuous or discontinuous (when intermediates are lost or destroyed) intermediates, which exhibit 'incipient speciation'. Members of such distinguished groups show graded variations, and in the absence of any strict regulation so far, it becomes serious problem to quantify the differences needed for a new species. Such examples are the 'sibling species', which acquired very little morphological differences but are isolated reproductively and hence are separate species. On the other hand there are populations with distinct morphological differences but are normally interbreeding. These are considered as same species.

(b) Hybrid breakdown

Occasional hybrids are produced by temporary or permanent loss of barriers thus bringing two once separated close species together. The resultant population is usually sterile with low adaptive fitness. Therefore they do not survive and do not create problem to taxonomists. If the barrier is completely lost in a local population, an extensive hybrid swarm is produced and introgression may occur. These are not formally recognized as species.

Taxonomists have assigned species status to many hybrids unknowingly and those were later rejected after thorough observation in nature (populations) when their hybrid nature became established.

Exceptionally two parental species fuse completely and give rise to a single new species. Such event is yet to be established and this will create problem in fixing their species status.

(c) Allospecies and semispecies

Earlier many taxonomists used the term semispecis to designate intermediates below species and subspecies. This may be due to less survey or the intermediates being lost from nature. Occasionally, due to presence of lots of differences from nearest species, groups of likely species is kept as allospecies. The taxonomists feel that they have attained species level differences but for further studies (collection and observation in nature) they keep them as member of superspecies.

(d) Sympatric and allopatric populations

Biological species concept cannot be tested for their gene flow in allopatric species. When two sympatric populations are brought closer artificially, there is normal fertilization and produces a progeny of reduced fitness.

Since the subject taxonomy is quite old, naturalists coined various terms and they were often misleading for their inherent meaning. Moreover some terms were used in different sense by few later authors. All these together made the explanation of the term species and many others quite perplexing. The meaning and definitions also need to be re-explained in the light of advancing science. To day many terms are well clear and the unusual fear in the study of taxonomy is gone. Rather it is now a most interesting subject in the days of molecular biology.

In the grammar of taxonomy, however, the terms, which are posing some problem with 'species', are phenon, taxon and category.

Taxon : Simpson defined taxon as 'a group of real organisms recognized as a formal unit at any level of hierarchic classification'. Mayr defined it as 'a taxonomic group of any rank that is sufficiently distinct to be worthy of being assigned to a definite category'. Some examples can make things understand better. If we say red crab, crow, sparrow, bony fish, reptile, king cobra etc. they will definitely mean some groups of concrete objects and any such group of population is called a taxon. This taxon (or the population) should have sufficient distinctness so that it can be ranked (categorized) in a hierarchy. A taxonomist will judge the worthy of placing such a taxon with other taxa of a category or to a different category. Thus the taxon name is a common word (not a scientific or taxonomic name). The words 'fish' and 'Pisces' both refer to a group of vertebrates; however the latter is the rank (category) in a hierarchy classification while the former is not. The former is a common English word (hence non- scientific). Similarly species, class, order are not taxon but category. Again *Bufo melanostictus* is a species and not a taxon while the name toad is a taxon of species rank. Thus the lowest taxon is a species. There are higher taxa such as birds or amphibians.

Phenon : The term was used by Camp and Gilly (1943) and assigned to 'a sample of phenotypically homogeneous organisms at species level'. In taxonomy, phenotypically reasonably uniform samples help in making more correct statement about a group of organisms (frequently a species). Although there is no generally accepted term to such 'uniformly phenotypically similar group' the term phenon is more appropriate to assign for this. The term 'morphospecies' should not be confused with phenon; former is a typological species recognized merely on the basis of morphological differences while phenon is a sample of phenotypically similar specimens. In the phenetic classification of Sokal and Sneath (1963), however, the term has a different meaning. The word phenon means individual variants and any species has many variants or phena. Phenon of one species may well resemble other species.

3.3.2 The Species Category

A *taxonomic category* is a level or rank in a hierarchic classification. A category contains members and all those taxa belonging to and assigned a given rank. In simpler way, a category consists of many taxa and these taxa have same level in a hierarchic classification. Thus genus, family, order etc. are categories and each of these contains one or more subordinate taxa (as a family contains one or more genera, a genus with one or more species). But a *species category* contains those members who belong to those species taxa.

, Over the past century, there were debates and controversies in the understanding of the term species. In fact, the species definition depends upon the requirements; it may be defined on the basis of attributes of the organisms constituting a species. The other way to define a species may be based on the process that gives rise to a species. Both definitions have merits and demerits. There are definitions, which have the attributes as well as the process of the origin of the species. However taxonomists prefer a definition based on attributes.

The lots of species definitions in the past are based or are outcome of several concepts-the species concept. Among the five species concepts, first two are considered more historical; still have some important facts in the understanding a species. The rest three are have much of the merits.

A. Typological species concept

According to the great philosopher Plato there are some 'universals' or 'types' on the earth the members of which are actually inhabiting on this planet and the diversity of nature which one finds is actually due to 'variations' of those few universals. This concept was continually accepted beyond post-Linnaean period. The approach to the meaning of species by this concept is based on the assumption that a species is constant in time, has a limit of possible variation and thus separated from other species by distinctiveness and finally members of a species share same attributes.

Thus the concept has some basic positive values but could not be accepted for the following facts:

a. Conspecific individuals may be morphologically distinctly different.

b. Sibling species are alike but belong to different species status.

c. Age differences, sexual dimorphism, polymorphism are some phenomena by which same species develop striking differences.

A taxonomist preliminarily may separate individuals into some species taxa merely based on outward appearance. These separated 'species' need to be verified through biological and other necessary studies.

B. Nominalistic species concept

Occam, the proponent of this concept and his followers (Buffon, Bessey, Robinet and Lamarck) believed that there is no need to express or designate anything as 'species'. They did not consider the presence of any 'real' universals, rather only organisms are present on the earth because they are the product of nature. Therefore such mental concept (ie. species) of man has no value. Bessey (1908), however, modified the concept and explained that 'species' has been invented so that species collectively refer to great number of individuals.

Such a concept was popular in France in 18th century and still today there are few adherents to this concept. Presently this is a historical one without any practical value. Because anyone knows man cannot create a species and only nature can create it. Species is different from any inanimate object created by man.

Nominalists, like any native, can group individuals on the basis of similarities. Thus they deny or did not acknowledge the evolutionary mechanisms (speciation, adaptation and others).

The similarities among members of a species population are due to common heritage and they are dissimilar from such members of another species population because of different ancestry. This hidden truth was absolutely ignored by nominalists.

C. Biological species concept

This entirely new concept of species emerges in 1750 due to continuous pressure from naturalists. The incompleteness of the earlier concepts lies in the proper understanding of true nature of a species. This concept is based on a philosophy that is different from that in inanimate world.

According to this concept, the widely used species definition of Mayr is as follows. "A species is a group of interbreeding natural population that is reproductively isolated from other such groups". Mayr explained that a species has three following properties.

(a) Reproductive community-which means that the members seek potential mates from among the members of this community and many factors or devices play important role fro successful intraspecific mating.

(b) Ecological unit-the members differ from each other for many features but all members together form a unit, which interacts with other such units in any ecosystem.

(c) Genetic unit-the members freely interbreed and whatever the diversity the individuals possess, these all variations together form a gene pool and all variants are part of this pool. Thus species has its own gene pool that is actually shared by its members.

This species definition is based upon biological parameters and that is why it is called biological species concept. There cannot be any comparison of a species with anything inanimate.

Gradually it became clear that species has independent reality and separated from other by its own population parameters. The essence of typological concept is that species has independent reality and of the nominalistic concept is that species are product of nature by the fact that members of a species population are different from other such by the presence of its own sets of attributes. However the biological species concept differs from previous two by the presence of genetic unity (because all species share a common gene pool) and its reality lies in the genetic combination that is an outcome of evolution and has been tested by natural selection.

This concept explains discreteness of the local species at a given time. The differences, according to Linnaeus (and typological concept), are due to differences in their 'types' (=species status) and in this way the evolutionary process has been ignored by typological concept. According to biological species concept a species is always plastic; it has the potentiality to undergo modifications required by the evolution.

The biological species concept is important to understand the functioning of a species as a genetic, ecological and ethological unit. These studies, when compared with other related species would clearly give an idea about how a species actually works in nature.

The above species definition, although widely accepted by evolutionists, is not free from criticisms. Its shortcomings were attacked by systematists (Sokal and Crovello, 1970; Cracraft, 1983; Donoghue, 1985). However a single definition for a dynamic object 'species' can hardly be achieved. The conflict between evolutionist and systematist lie in the fact that species should be considered as evolutionary unit (evolutionist) or as reproductive unit (systematist). Although the currently accepted basic unit of taxonomic differences is a population, many taxonomists are forced to rely differences among individuals or subspecies or local species. In nature we cannot judge reproductive isolation in allopatric population, which is a major bombshell to population concept..

Difficulties in the use of biological species concept

Apomictic population

Biological species concept is difficult to apply to apomictic or asexual groups that show uniparental reproduction by hermaphroditism, apomixis, parthenogenesis, budding and gynogenesis. Most of such apomictic groups show facultative sexuality depending on endogenous or exogenous factors thereby making things more complicated. A thorough knowledge of all sexual and asexual forms can only unfold the true nature of the organism.

Uniparental reproduction is observed in lower invertebrates (including insects) and lower vertebrates (even in reptiles). Such lineages are termed *agamospecies*, *binoms* (Grant, 1957) or *paraspecies* (Mayr, 1987). In the definition of population, it will not be much contradictory to include all asexuals with sexuals. But for taxonomists it is difficult to assign a status to a strain, stocks, pure lines, biotypes of an organism. Mayr (1963) clearly stated that these are not any sub-division of biological species. According to Ghiselin (1987) as well as Mayr (1988) the application of the word 'species' is not justified to such uniparental population.

The above situations are solved separately depending on the reproductive behaviour of apomictic organisms as follows.

(a) Permanently uniparental population :

Numerous studies on similar asexual groups of individuals revealed that some have attained so much perfection towards this line of evolution that they became permanently asexual groups. Once originated from sexual ancestors, they have deviated so much in time that their genetic combinations are different among different asexual populations and by no means they can perform genetic exchanges. Thus they are reproductively isolated. They are also morphologically well differentiated with a distinct gap from the near relatives. This discontinuity has been favoured by natural selection. Such well-separated uniparental populations are regarded as separate species (= *microspecies* of Mayr) than conventional use of the term '*race*'.

(b) Thelytoky :

This is a form of parthenogenesis in which males are non-functional or do not exist at all. White (1978) observed that in a population of similar organisms, there are two distinct sub-populations depending on the behaviour of chromosomes during meiosis; one shows tendency towards homozygosity and the other towards heterozygosity. Nature selects heterozygosity over homozygosity and the latter is rarely seen in fewer groups. There is even coexistence of thelytoky alongside bisexuality. White mentioned that, as a measure of survival, the interspecific hybrids took the route of parthenogenesis (thelytoky) and they are producing heterozygosity. This event seems to be recent in origin *e.g. Cnemidophorus*, a lizard of South-Western United States and Mexico). Thelytoky in some salamanders, fishes and in one grasshopper evolved to get rid of difficulties arose by hybridization.

(c) Mixed population of both sexuals and asexuals

Aphids, *Daphnia*, rotifers and digenic trematoda are known to produce in both procedures. Species status is not given to temporary clones produced asexually. Sometimes in aphids asexuals are known to be permanent and never regain sexuality and they are morphologically and ecologically quite different from sexuals. Whether they have sufficient genotypic variation for a separate species status is debatable.

Biological species concept is similarly not applicable to Protista or Prokaryotes where genetic exchange does not occur. However there are evidences of conjugation among bacteria and this led to the concept of '*genospecies*' (a group of bacteria able to exchange genetic material).

(d) Allotetraploids

These are obtained by chromosomal doubling of the sterile hybrids and become fertile and produce cross- fertilizing allotetraploid progeny. The new progeny has sufficiently distinct characters and are given species status although the route of their origin may be known.

D. Evolutionary species concept

This concept was proposed by Simpson (1961) and has undergone many modifications. The concept is as follows: "An evolutionary species is a lineage (an ancestral -descendent sequence of populations) evolving separately from others and with its own unitary evolutionary role and tendencies". This definition is concerned more with phyletic lineage. Simpson attempted to solve the species definition by adding to it the time dimension, which was deficient in biological species concept. Wiley (1981) provided a revised definition as follows " a species is a single lineage of ancestral descendant populations which maintains its identity from other such lineages and which has its own evolutionary tendencies and historical fate".

Here 'maintains its identity' refers to reproductive isolation. This definition is that of species taxon, not of the species category (Mayr and Ashlock, 1991).

Wiley explained that an evolutionary species is a branch or part of branch in an evolutionary tree and due to its own 'evolutionary tendencies' the branch may produce smaller branches and all (the branch and its smaller branches) will show historical fate. Here the relationships of the descendant populations of that single branch are not clearly understood. While Simpson separated every lineage on the basis of reproductive isolation, Wiley believes that 'no presumed separate, single evolutionary lineage may be subdivided into a series of, ancestral-descendant species'. Therefore the disadvantage of Wiley's explanation is that one cannot predict or know the fate of an extant lineage. Many such lineages have produced descendants in evolution. If we strict to only one lineage (for the sake of definition) we cannot proceed from one species to a future descendant species.

According to this concept the evolutionary role of cryptic species is not possible to estimate because of the similarity in their evolution. Another problem is that the natural hybridization of agamospecies (for example plants) produces lineages for their survival, which are quite different than those normally produced in biparental species. These progeny survive in nature successfully. Thus evolutionary concept has not explained their evolution.

E. Phylogenetic species concept

To avoid the strictness of breeding potentiality of biological species concept, Cracraft (1983) proposed this concept and put stress on genetic and behavioural criteria of organisms. Subsequent authors also modified the present concept later and the widely discussed version is: 'a species is the smallest possible group of sexually reproducing organisms that possesses at least one diagnostic character, which is present in all group members but is absent from all close relatives.

Biological species concept depends on biological characteristics but this concept is more based on diagnostic characters acquired through evolution (Donoghue, 1985; Baum, 1992). Such a group of species population must be sexually reproducing; it has acquired fixed genetic diagnostic features through evolution which are absent in all close relatives.

The basic drawback of this concept is that any species may be paraphyletic considering the plesiomorphic characters. This was avoided in modified definition by adding requirements for monophyly (Mishler, 1985; De Queiroz and Donoghue, 1988, 1990). Another deficit is that distinct populations of many species would be raised to species rank by considering 'smallest possible group' (Mayr, 1992). Wheeler, 1990 pointed that in that case the estimate of the number of species on the earth would be far greater than it is by the more traditional biological species concept.

F. Species recognition concept

Paterson (1985) and Lambert *et al.* (1987) proposed this concept to overcome some demerits of biological species concept and also claimed its superiority. The definition is: "a species is a population of biparental organisms, the members of which share a common fertilization system". Here fertilization system includes all biological parameters of the organism, which act together and ultimately enable fertilization to increase in number. The organism actively (by courtship etc.) or passively (gamete movement, either positive or negative gamete recognition) recognizes its partner.

Post-fertilization barriers are not considered in this concept and this may produce unsuccessful progeny. Butlin (1987), Coyne, Orr, Futuyma (1988) and Mayr (1988b) suggested that this concept has more problems and is based on misinterpretation of biological species concept. This concept gained no popularity and is invalid.

Discussion

Mayr (1957) has pointed out that morphological distinction is secondary attribute of a species and the primary and most vital aspect is the biological distinctiveness. The former may be changed or acquired secondarily.

Christoffersen (1995) proposed his *'ontological (theoretical) species concept* in which interbreeding nature of a species has been stressed. The definition of species given is 'a species is a single lineage of ancestral-descendant sexual populations genetically integrated by historically contingent events of interbreeding'. This concept is almost similar to the revised evolutionary species concept of Wiley (1981).

The *'operational (epistomological) concept of species* proposed by Christoffersen is actually a modification of the concept of Cracraft (1983, 1987), Davis and Nixon (1992) and Wheeler and Nixon (1990). According to this concept the species is 'an irreducible cluster of sexual organisms within which there is a parental pattern of ancestry and descent and that has diagnosable distinctiveness from other such clusters by a unique combination of fixed characters.

Thus the former concept of Christoffersen is transformational (dynamic) where a species is formed at a node of a phylogenetic tree and the latter concept is static, where a species is the smallest recognizable population produced as an outcome of former process.

The definition given by Florkin (1964) is that 'a species is a group of organisms with more or less similar combinations of sequences of purine and pyrimidine bases in their macromolecules of DNA and with a system of operators and repressors leading to the biosynthesis of similar amino acid sequences'.

Emerson (1941) suggested that a species is 'which has evolved or evolving, reproductively isolated and genetically distinct groups of natural population'.

Most of the concepts discussed above overlap each other and one can find one is suitable for a group of organisms while another for another group. So no one concept can fulfil all the requirements demanded by a species definition. Hence Mishler and Donoghue (1982) suggested that since no single concept can cover all the taxa, systematists have to adopt on all concepts together and there should not be any biasness for any specific concept.

After the development of numerical systematics and cladistics in 1960s, lots of exercises were done to arrive to the definition of a species (Butlin, 1987; Christoffersen (1995); Coyne, Orr, Futuyma, 1988; Cracraft, 1983, 1987; Davis and Nixon (1992); De Queiroz and Donoghue, 1988, 1990; Emerson, 1941; Mayr, 1988b; Lambert et al., 1987; Mishler, 1985; Nixon, 1992; Paterson, 1985; Wheeler and Nixon, 1990; and Wiley, 1981).

The essence of the different species concepts may be summarized as follow.

1. Species is a group of interbreeding population.

2. Species has its own gene pool highly protected from other pools by various isolating mechanisms. When the mechanism fails and hybrids are produced, they take a path of evolution different from parent.

3. A species must be sufficiently distinct from its nearest relative by the presence of distinctiveness from other such clusters by a unique combination of fixed characters.

4. Species has its own role in evolution mate finding, migration, adaptation and other forces of the nature produce subpopulations with different gene frequencies. These will show distinctiveness and separation sufficient to attain a new species status.

5. Caution should be taken for those populations, which have intermediate or transitional habitat or environment where different organisms show different degrees of interbreeding potentialities.

6. Agamospecies, unisexual or hermaphrodite species mostly develop mechanisms enabling cross-fertilization to revive own gene pool that has undergone wear by homozygosity. However presently we find many asexual species that flourished in present environment. It is difficult to say whether these represent intermediate stages in evolution of these species or they are more permanent towards a new trend in evolution is uncertain. It is more probable a route to extinction than any further evolution but are favoured by

natural selection in relation to present day environment. Any sudden change in the environment will alter their gene frequency when they may take active role in speciation.

7. Since the various experimental results depend upon true identification of the species worked upon, any experienced taxonomists should remember the definition of a species. Often it is said that 'a species is that which a competent taxonomist says a species'. This simple phrase hides many factors to determine a species.

3.3.3 Infra-species category

In taxonomy, there is strict use of infraspecific category. Only subspecies category is used with certain cautions. But still many scientists use following infraspecific terms, which are not taxonomically recognized.

Subspecies

Linnaeus coined the term 'subspecies' to describe any deviation from the type of the species. Early taxonomist indiscriminately used to designate variety to any variation because there were no clear-cut rule to decide how far differences may be taken for a variety. Thus many earlier 'variety' were mere expressions of a species population. This term is obsolete today.

In nineteenth century the term subspecies replaced variety. Ornithologist Schlegel (1844) coined the new term 'variety'. Subspecies is actually a category below species and is different from latter. Kant (1775) advised to separate species from subspecies or variety.

Introduction of subspecies and its recognition by International Rules of Zoological Nomenclature provided the trinomial nomenclature. In fact Darwin's "Origin of Species" (1859) provided examples of variations. It was an impetus to later taxonomists to use the term. But too many names of a same species became not only an unwanted heap in zoological nomenclature but also confusing to taxonomists. Hence Inger (1961), Wilson and Brown (1953) proposed the withdrawal of subspecies category. Subspecies is a "pseudotaxa" which cannot be classified (Blackwelder, 1967).

Mayr defined subspecies as "an aggregate of phenotypically similar populations of a species inhabiting a geographic subdivision of the range of that species differing taxonomically from the other population of the species". A trinomen is used to designate a subspecies.

The various populations over different geographical areas face differences in ecosystem. Genetic differences accumulate due to continued exposure to those different environmental features over a long period. In spite of overall similarities, these subpopulations become different from one another both in genotype and phenotype. Their differences in biochemical, morphological or genetic parameters are tested for statistical differences and thus must reach a taxonomic level sufficient to designate them as subspecies. It may not be true that each geographical sub-population be a subspecies. Again individuals at the zone of intermingle of two geographical areas show intermediate features of two subspecies. Species or subspecies do not overlap rather their extensions of occurrence meet at a place. In this way subspecies is a collective category.

With the introduction of polytypic concept (Beckner, 1959), it is widely accepted that genotypic variation within allopatric species exists. This concept, in turn, gave rise to population taxonomy which reduced the excess burden of naming many 'different' species. This also simplified animal classification. Not all species are polytypic and there are many monotypic ones. This concept clearly gave the solution to the fact that many previously recognized morphospecies were not reproductively isolated and hence not separate species; they are now treated as subspecies (not as a taxonomic category).

The recognition of subspecies is difficult and only experience and sufficient data can solve the status. Generally speaking it is an interbreeding group with various forms of differences (*e.g.* morphological, geographical, ecological, physiological and such others) which give it species like distinctness (Grant, 1960). The amount of differences is always debatable and the matter is left with experienced taxonomists who actually deal with a lot of materials from various localities.

Rothanaler (1954) advised that two subspecies must be separated completely over a long period. The barrier must influence to create differences among the separated populations according to the need of modified environment.

The other feature of a subspecies is that it is an isolated gene pool and may behave as incipient species. The subspecies category provides possible phylogenetic trend of a polytypic species (Grant, 1960).

Benefits of the use of subspecies category are strongly felt by Goldschmidt (1940), Simpson (1961), and Mayr (1969). They suggest its rank different and below a species category. While subspecies are very similar and not reproductively isolated, the species are different from each other through isolation mechanism.

Starting with a species we can trace the origin of subspecies that evolved through breakup of the original population by barriers and dispersal. These isolated populations, through ages, attain sufficient genetic and morphological differences to become finally reproductively isolated. Thus a new species can be formed very near to the original species.

Various authors used the term subspecies to specify their species features and those, according to Edwards (1955) are as follows.

(a) *Geographical subspecies* is formed by separation of members of a species population during reproduction or migration into different geographical areas where they adjust to new environment and gradually acquire differences except for reproductive isolation.

(b) *Temporal subspecies* are those different fossils of different ages. These, however, may be contemporary and geographically separated and hence may belong to same species. Sometimes geographical races replace each other owing to climatic changes and are discovered in succeeding strata. Fossils help to understand relationship and also the evolutionary trend. However subspecies is always a classificatory device.

Populations of a species active in different era in past geological periods may have been totally separated and thus were not synchronic. Their reproductive isolation may be assumed complete. Their differences in genetic combination are directly proportional to the time elapsed, except the periods of mass extinction when there was rapid speciation. Their genetic distances can be calculated by modern technique (DNA fingerprinting) and there should be significant taxonomic differences to call one a subspecies.

Mayr (1969) advised that geographical and temporal subspecies should not be used as separate terminology. It is not possible to determine whether these separate subspecies are precisely contemporary or not. Even if any sequence of subspecies is found from same locality they may not be purely temporal

If an infra-specific population becomes isolated temporarily during mating but nevertheless crossbreed freely under sympatric condition with the members of any subpopulation, then these are often regarded as temporal subspecies. This type of definition may create confusion with fossil subspecies (temporal subspecies of Mayr, 1969).

(c) *Seasonal subspecies* are the members of two distinct sympatric populations of a given species that show sexual maturity at different periods of a year. Thus the two populations are kept isolated and no genetic interchange takes place. Therefore, if they never meet together and there is no genetic exchange, they should not be considered as subspecies but as true species. Often this has been known as *Annual subspecies.*

(d) *Ecological subspecies* are micro-geographically isolated but are freely and naturally interbreeding under sympatric condition; these occur in different biotopes or populations of biotopes. These are indicated on topographic map or faunal maps which show their micro-geographic habitats.

(e) *Polytopic subspecies* is a geographically heterogeneous subspecies. Several unrelated and more or les widely separated populations may show convergent adaptation of very similar phenotype although they vary widely in their genotypes. Such different subspecies are combined into one subspecies taxon called polytopic subspecies. Due to disadvantage (since they belong to different species category) polytopic subspecies concept is usually not used in taxonomy except to refer to heterogeneity in a collection of subspecies quite superficially.

Difficulties in the application of subspecies category

The use of subspecies category helps a lot to understand the polytypic species. However, this has been used differently by different authors without restricting to its definition or by misunderstanding or has misused this category. Hence Wilson and Brown (1953) pointed the following disadvantages:

(a) There is no uniform opinion to determine the degree of differences or amount of distinctiveness.

(b) Even within an established subspecies there may be several microgeographic variations.

(c) Phenotypically inseparable allopatric populations may develop independent to each other and such populations cannot be recognized as subspecies although they should be by definition.

(d) Many characters show their own independent trends of geographic variation.

In spite of usefulness to taxonomists, the three criteria remained unsolved and there are the nature of distinctiveness, interbreeding nature (in allopatric population) and weightage of characters used to differentiate. If the populations are separated naturally there may not be genetic exchange under normal condition and their potentiality to reproduce normally cannot be tested. It may be true that they breed normally if brought closer. Time is an important factor and separated subpopulations, in future, may exhibit reproductive isolation. It should be remembered that members of all subspecies populations belong to same species and they are convenient device for intraspecific classification. Variation in population is a natural phenomenon and the degree of such differences is used to recognize subspecies. Only this much is the utility of subspecies. The different subspecies are similar for most of the characters and they differ in fewer characters (genotypically and phenotypically). These characters are mostly adaptive in nature and probably have no role in evolution.

3.3.4 Other infraspecific categories in relation to subpopulations of a species

Variety

As discussed earlier, this term was commonly used in Linnaean period. Any such designation (variety) after 1960 is not recognized by zoological commission. There were no distinct criteria to differentiate a subpopulation as variety.

Race

It has been used in different sense among scientists. Taxonomists working on insects, birds and mammals used geographical race and subspecies synonymously. In general, race is a local population within subspecies.

Subpopulations of a species inhabiting different ecosystems are called ecological race and thus every subspecies becomes an ecological race, since the different localities differ in ecological parameters. But often no significant taxonomic differences are available although they differ in their ecological needs. Parasites and plant feeders may become isolated by living in or on hosts and gradually becomes separated from original group. Moreover there is a tendency to evolve according to the nature of the host's resistances (such as host-parasite interaction and insect-plant co-evolution etc.). These separated progeny with drastic reduction in gene flow will be equivalent to geographic race.

Strickberger (1996) defined race as 'a population or groups of population in a species that share a geographically and/ or ecologically identifiable origin and have unique gene frequencies and phenotypic characters that distinguish them from other races.'

The sharp differences between race and subspecies may need clarification. On closer examination, following characters of a race may be observed.

1. Race is not taxonomically recognized but subspecies is.

2. Expected rate of more fertile progeny is higher in races than in subspecies. Because in subspecies the gene frequency is altered to greater extent.

3. Race is a vague and controversial term and used indiscriminately. It is frequently used to describe any form of minor phenotypic changes within a subspecies.

Cline

Huxley (1939) used this term to describe a character gradient or gradual changes of a character which is usually observed in contiguous population. Variation in any character is clinal and this is usually gradual (smooth) or rarely sudden (step clinal). Population showing smooth cline should not be regarded as subspecies. However two subspecies are found at two extremes of a cline where changes are taxonomically significant.

Isophene is the stretch along which all members show much similarities and this line, hence, perpendicular to the cline.

Morphotype

This is a very superficial and non-taxonomic term applied to a sample within a subpopulation. It is a 'distinguishable sympatric and synchronic interbreeding populations of a single species' (Edwards, 1955).

Rassenkreis, formenkreis and artenkreis

Rassenkreis (Rensch, 1929) and formenkreis (Kleinschmidt, 1926) are synonymous and they refer to the polytypic subspecies (Mayr, 1969). Both are not accepted by Zoological Commission. Kleinschmidt defined formenkreis as 'a collective category of allopatric subspecies or species' and in paleontology it is 'a group of related species or variants'. However it is established that a species is quite different and belongs to a higher category; it encompasses all sorts of geographical variations of its members. Rassenkreis was given to a genetic species with a series of intergrading but local populations and only those at extreme ends show wide gap in gene frequencies and fail to interbreed (isolation is complete). Rensch later redefined formenkreis and proposed the term artenkreis. This was described as a genetical species, which is a local undivided geographic race and does not exchange its gene pool with adjacent subpopulation.

Infrasubspecific and superspecific terms

Deme

Mayr described *'deme'* as only one subspecific category and it is not taxonomically recognized. Zoologists consider deme as evolutionary unit inhabiting a small local ecosystem.

In earlier days, taxonomists proposed and used several other terms to designate variations among subspecies. With the rise of population biology, such subdivisions were proved to be useless. Mayr also advised not to recognize formally every local population showing some differences. This is because there is always a tendency in individual variation or variation in subpopulations inhabiting only few miles apart.

Superspecies

The literal meaning of the term artenkreis is 'circle of species' and to avoid confusion, Mayr replaced it by an international term superspecies. It is defined as a 'monophyletic' group of closely related and largely or entirely allopatric species'. Mayr described it as polytypic species, the members all descendant from a common ancestor. They include, in broader sense, both allopatric and those in areas of geographical contact (*parapatry*) still maintaining reproductive isolation. According to Simpson (1961), a superspecies is 'groups of populations that seem on other groups (morphology, ecology etc.) to have passed beyond the point of potential interbreeding and to have acquired separate evolutionary roles, but that are not demonstrated to have done so by the more conclusive evidence of remaining separate when sympatric. It is to be presumed that they are still near the critical point of speciation, that of definite isolation, and it cannot be quite certain whether they are really past that point and are not just below it. They are nascent species, when survive, shall collectively form a subgenus or eventually a genus but have hardly yet reached that degree of divergence and expansion'.

Superspecies has a unique gene pool and it is not interchanged with its close one. There is usual gradation of ancestral characters and it acquires gene frequency different from relatives. The number of the members of such a species is very low initially and it dynamically struggles to increase in number. Characters of higher weight are developed anew or through modification of some characters. Thus it occupies a higher category (subgenus or genus).

In spite of this meaningful event in speciation, taxonomists do not feel to insert a new category above species. There is also a problem of explaining the sharp difference between a species and superspecies.

Superspecies is not taxonomically recognized although it was used in many earlier monographs and other publications. Superspecies is a transitional event, not a final form on which a category may be established. Some authors, however, felt the usefulness of the term to study zoogeography and speciation events.

3.4. Theories of biological classification, hierarchy of categories

Man and animal study anything around themselves by self or by learning. He needs to classify insect, plant, water, land, poisonous and non-poisonous objects and such others for future reference or to communicate to others. In the absence of any classification, simply knowing and understanding the multitude of objects would leave everything beyond control. From the period of early philosophers till recent, classification of living and non-living objects is continuously modified according to the availability of further knowledge.

So far there are one and half million described species, more than twelve thousand fossil species and there is a continuous downpour of newer species description. A classification, hence, is dynamically accommodating all these species according to their relationships. A good classification is a system of enormous amount of information about organisms which are readily and conveniently available to a scientist. Information means the characters some of which are exclusive for a group. Selection of character is a vital matter in classification.

Mayr defined zoological classification as 'the ordering of animals into groups on the basis of similarity and relationship'. According to Mayr and Ashlock (1991), 'a biological classification is the ordered grouping of organisms according to their similarities and consistent with their inferred descent'. Such a definition makes classification natural because it reflects the evolutionary pathway of the organisms.

3.4.1. Differences between classification and identification

Classification	*Identification*
1. It is the delimitation, ordering and ranking of taxa.	1. It is the determination of the taxonomic identity of an individual.
2. It deals with population or groups of populations and is based on maximum available characters.	2. It deals with individuals and is based on fewer characters, ideally single.
3. It is based on inductive reasoning.	3. It is based on deductive reasoning.
4. It is the ordering of the vast diversity of nature or any part of it into sets or groups.	4. An unidentified object is fitted into a given set of taxa.
5. Quality of classification depends upon the theory on which it is based.	5. Quality of identification depends on the quality of classification on which it is based.

According to the traditional definition, classification is 'the grouping of objects into classes owing to their shared possession of attributes'. Such a definition clears the meaning of classification and identification.

3.4.2. Properties of good classification

1. Classification should be natural, *i.e.,* instead of being based on arbitrary characters, it should reflect descent. This was what Darwin realized.

2. An ideal and acceptable classification will rank all animals according to their characters

3. Classification is based on a theory by which one can easily understand the relationships between a close or distant taxon.

4. It will store information on the structures of the taxa and the analysis of that information will help to trace the phylogeny of the taxa.

5. Since classification is based on relationships, therefore similar organisms (hence organisms having similar genotype) will be grouped together. If genotype of an unknown organism is known, then one can predict about the characters of that organism. However such predictions are not always correct, because taxa may be polythetic or undergo specialization.

6. An advanced (*i.e.* recent) organism will have more complex genotype. Because such organism will have more characters and will be categorized in higher rank.

7. Classification is alterable; like othe science, classification will be revised or modified on the basis of newer findings.

8. Classification contains information about many structures the functions which are unexplainable in the recent context. These are present as a continuum from the ancestor. These characters help to identify homologous structures.

9. Classification constructs the most homogeneous groups; they are descendant of the nearest common ancestor.

3.4.3 Comparison of artificial and natural classification

Artificial classification	Natural classification
1. Proposed during early stages of the development of taxonomy and the proponents were Aristotle (384-322 B.C.), Lamarck (1707-78), Cuvier (1769-1832) and others.	1. Proposed later (post-Darwinism) and proponents were Simpson (1959, 61), Cain (1959a) and others.
2. It is useful in classifying inanimate objects.	2. It is useful for organisms, which essentially shows evolution.
3. It is based on priory weighting of taxonomic characters.	3. It is based on posteriori weighting of taxonomic characters.
4. It is based on convenient and diagnostic characters with no stress on relationships.	4. It is based on diagnostic or hidden characters with stress on relationships.
5. This classification usually based on fewer, even single character (like "identification").	5. This classification is not based on fewer characters; here evaluation of the totality of characters is done.
6. No emphasis is given on the presence of constant characters.	6. Emphasis is given on the presence of constant characters (*i.e.* correlated or aggregated characters).
7. It is a downward classification based on logical divisions (by dichotomy). This system dominated up to end of 18th century.	7. It is an upward classification based on assembling species (by inspection) into groups of related species and forming a hierarchy of higher taxa by again grouping similar taxa of the next lower rank. This system evolved by middle of 18th century.

Artificial classification	Natural classification
8. Since it depends on any unwisely selected characters, this can never depict any relationship of organisms and therefore cannot help to find out the phylogeny.	8. It reflects most closely the actual relationship of the included taxa. Therefore it clearly helps to find out the phylogeny.
9. It ignores the fact that groups of organisms are related by descent and possesses a unity by the shared portion of their DNA heritage.	9. It signifies and explains why and how groups of organisms related by descent because they possess a unity by the shared portion of their DNA heritage.
10. This classification never thought of and even hindered the search for missing link and common ancestors.	10. This classification put scientists to work in field, search their ancestral types, missing links, to study comparative aspects like embryology, systematics, anatomy etc., and thus widening the array of taxonomic research and clearly explained the theory of evolution.

3.4.4 Upward and downward classification

Downward classification

The principle of downward classification dominated up to the middle of eighteenth century. Essentialists (Plato, Aristotle and later Linnaeus) believed species as unchanging types (essence). Based on this concept, they proposed the logical subdivision of animal kingdom by dichotomous branching. This is on the presence or absence of certain characters; such as presence of hair or absence of hair, presence of shell or its absence and similar dichotomy. They, therefore, included many unrelated groups together and produced an artificial classification and that was an identification scheme started at kingdom down to species.

Linnaeus made significant contribution to his familiar group (Insect) most of which is still in use. But for chordates this was poor.

Upward classification

The shortcoming of downward classification was soon understood and after middle of eighteenth century, it was converted to upward classification. Buffon (1749) said 'it would seem to me that the only way to design an instructive and natural method is to group together things that resemble each other and to separate things that differ from each other'.

In this method, species were assembled into groups of similar or related species and forming a hierarchy of higher taxa by again grouping similar taxa of the next lower rank. Taxa were delimited by evaluation of numerous characters and *posteriori weighting* (weighting is a method of inferring the phyletic information content of a character. A character of high information content appears to be a product of a major and deeply integrated portion of genotype. Examples are the complex character, joint possession of derived character, consistency and constancy).

3.4.5 Theories of classification

Mayr (1969) recognized five theories and among these, first three are pre-Darwin. These are *Essentialism, Nominalism, Empiricism, Cladism* and *Evolutionary classification.* Two more theories are mentioned elsewhere are *Natural classification* and *Omnispective classification.* Mayr and Ashlock (1991) recognized three schools of macrotaxonomy- *Phenetics, Cladistics* and *Evolutionary classification.*

Recent books do not mention the pre-Darwinian theories. It appears that brief knowledge about those historical theories will give an idea of the evolution of the later theories. The current three are the theory of *Evolutionary Classification, Numerical Phenetics* and *Cladism.*

(a) ***Essentialism (Aristotle's natural sytem)***

According to Aristotle (384-322 B.C.), all members of a taxon reflect the same essential nature, *i.e.,* they conform to the same type; the number of the basic types is fixed (= constant) and the variation is considered to be irrelevant. All essentialists agreed with Plato that by pure knowledge, the hidden nature or form or essence of things are to be discovered.

Aristotle is called the father of biological classification. The principle was so profound that their method of classification continually practiced for next two thousand years. Many of the term they applied are in use to day. However, the classification was not orderly and consistent. The demerits are: (i) there is no principle to discover and identify the essential characters; (ii) species is a descendant of an ancestor and they are related to each other; (iii) variation is an innate property of a species; (iv) no species is fixed in nature; (v) many species of some higher taxa may not exhibit those essential characters and (vi) 'characters in common' are not rigidly taken into account. These are the wrong ideas of this theory.

-(b) ***Nominalism***

According to this concept there is no such things as species, type, groups, class or universal and believed that only individuals exist. These terms are artifacts of human mind. Classification of plants, animals and inanimate objects are based on the same principle of reasoning of sense data. But we know that the descent of organisms shows a relation due to the presence of shared attributes. This principle was not adopted by this school and also misinterpreted this basic nature of organisms.

But we know that animals are natural groups and not a product of human mind. Similarity among related groups is due to the possession of shared attributes and they evolve from common ancestor. The classification of biological object depends upon biological criteria and thus it is different from inanimate objects.

(c) *Empiricism*

Linnaean classification continued for about one hundred years till the publication of Darwin's *Origin of species*. Scientists felt that a classification must be based on totality of characters, not just few or even one. Renowned scientist of this period is Lamarck but Cuvier's contribution was more practical although the latter was a mixture of previous concept and some very sound practical taxonomy.

Empiricism, however, ignores any principle for classification; rather intellectual evaluation of as many characters as possible will produce a natural classification. The consistent disagreement to any principle made this theory untenable.

(d) *Evolutionary classification*

Darwin's publication first gave the world the basic foundation of evolutionary mechanism and the meaning of the 'naturalness' of animals. Soon the basis of classification got the proper guideline and a new dimension. The theoretical basis for classification given by Darwin was 'groups within groups' and explained that separation of taxa must be based on branching and ranking of taxa depends on degrees of modifications they have undergone in time. Darwin also proposed the concept of constant presence of some characters in related forms (*posteriori weighting*) and constant association of several characters. The last two principles opened up the best guideline for a natural classification.

Thus evolutionary classification is based on Darwin's principles: one is genealogy (common descent) and degrees of difference or modifications. According to this theory, natural groups of organisms (*i.e.* taxa) exist in nature. Darwin explained that mere similarities are not enough criteria; rather reasons for such similarities are to be explained by a natural classification. Thus scientists have to 'discover' the taxa and not have to 'create' them. Characters are the evidences, not that characters are classified. The evolutionary classification combines phylogenetic branching with the degree of evolutionary divergence among different taxa, which is the best combination, required by a natural classification.

The methodology of this *classical or evolutionary classification* has been explained by Cain and Harrison (1960), Simpson (1961), Mayr (1969), Bock (1977), Wiley (1981) and Farris (1977). Mayr and Simpson developed the principles fully in their papers and the evolutionary school is also called Simpson-Mayr school.

A difficult approach in evolutionary classification is to combine 'similarity' and 'descent' and to prepare a classification on the basis of both. Evolutionary taxonomists construct a provisional classification based on overall similarity and thus show all taxa in a classification. Thereafter such taxa are interpreted for monophyly, *i.e.*, for their origin from nearest common ancestor. However, the last part can be done by cladistic method.

(e) ***Natural classification***

According to Blackwelder (1967) animals are placed into as many groups or subgroups as are the similarities. Here groups are recognized on the basis of maximum common attributes and such groups are limited (*i.e.*, separated from others) by discontinuities in the diversity and by judgment, deductions about the correlation of other features will come up. Smith (1965) and others explained the natural classification as a phylogenetic one, which shows evolutionary relationship of the groups.

The above statement is not different from the first part of the principle of evolutionary classification (phylogenetic approach or ancestral-descendant relationship). Discontinuities in diversity may be due to various reasons and these will not always give correct deductions. The second part of the evolutionary classification i.e., the degree of divergence in time is not explained by this theory.

(f) ***Omnispective classification***

Blackwelder (1967) modified the concept of natural classification and proposed this omnispective classification. According to this concept, an experienced classifier initially works upon all available characters to classify the organisms into groups. Thereafter only few vital characters are selected for grouping and separation of groups.

Such a practice may help the taxonomists but there is possibility to produce an incorrect classification. Because without considering the weightage of characters, the classification tends to be artificial. The importance of ancestral characters for grouping and characters responsible for monophyly (*i.e.*, branching) are expected to be used in a natural classification.

(g) ***Phenetic classification***

Principles of Numerical Taxonomy (Sokal and Sneath, 1963), which is later known as *Numerical Phenetics* (because cladists also uses numerical methods) and more commonly as *Phenetics* is the first to provide a technique to draw phyletic lineage on the basis of similarities and differences. They adopted Darwin's principle of similarity due to common descent and claim that 'overall similarity' can be obtained from the recording of similarities and differences in large number (>60).

In 1973, Sokal and Senath published the second and the revised edition of this theory. They defined the theory as: 'Numerical Phenetics is the methodology of assembling individuals into taxa on the basis of an estimate of unweighted overall similarity'.

Pheneticists explained the merits of their theory as follows :

1. There is no requirement of knowledge of the taxa to be studied; the person should have the ability to find out as many characters as possible and to quantify them. So trained technicians will collect data from specimens and all question of systematics will be answered (Ehrlich 1964).

2. Computer programmer can fit the observed similarities and differences.

3. Gilmour (1940, 1961) said that in phenetics, the number of characters used is far more than traditional system and this eventually would produce a more natural classification.

Pheneticists believe that theory-free inductive approach of their theory would create correct classification. They adopted Bridgman's (1945) philosophy of 'operationalism', whose 'clear and possible (operational) instructions, replaced biological theories. and explanations. Pheneticist's operational method denied reference to species and thus they, in principle, adopted the nominalistic philosophy. They are giving equal weightage to all characters and such a classification may become artificial. They replaced species by the concept of '*operational taxonomic unit*' (OTU) and an OTU may be individual or population. Phenotypically different individuals are sorted out into different OTU. Thus pheneticist faced the crisis of explaining the individual variations and sexual dimorphism.

A phenogram is obtained as end product of clustering process. There are several methods to convert a phenogram into a classification (Rohlf and Sokal 1981; Mc Neil 1979).

Merits of phenetics

1. Phenetics opened the window to classify above species level and removed the dissatisfaction of traditional approach.

2. Introduction of computer in taxonomy is their credit and this proved to be efficient in making quick and error free comparison of data matrix for similarity and differences among taxa and inspired to search more differentiating characters.

3. Phenetic approach is more suitable for closely related taxa originated from common ancestor and thus with similar evolutionary roles and hence, abundant homoplasy.

Therefore, for each apomorphic character a separate assemblage of species can be recognized. Daly and Balling (1978) used this method to classify African and European honeybees and their hybrids.

4. Although phenetic method was not accepted by later systematists in animal classification, this has been consistently applied in plant taxonomy and molecular biology.

Demerits of phenetics

1. The method is laborious and time consuming because it has to score more number of characters than traditional method.

2. There is no scope to pay attention to the weightage of characters.

3. Not all animal taxa provide enough characters and there phenetic method faces trouble.

4. Addition of new character requires fresh calculation and may reject earlier decision.

5. OTU lost biological sense and phenetic concept goes back to pre-Darwin age.

6. Variation of organisms is not accepted as natural phenomenon of members of a given taxon.

7. Lack of theoretical base in the choice among clustering method, selection of character, arbitrary assignment of values and choice of clustering method; all depend on personal choice. Hence Sokal (1985) felt that 'different clustering methods yield different fits by cophenetic correlation coefficients to the same resemblance matrix'.

8. The choice of different algorithms (computational methods) yields different phenograms (Minkoff 1965); Felsenstein 1983; Presch 1979).

9. Unweighted similarity method will force pheneticists to fit sibling species in a single OTU.

10. Parallel, convergent and reversed characters are equally treated without paying attention to the cause of their origin. This leads to wrong clustering.

11. Numerical values of phena in different taxa cannot be compared to each other. This value will change when compared to another set of taxa. Thus no universal scale can be established. 'Phenetic technique will not reach perfect congruence of classification when these are based on different sets of characters (Sokal)'. Ghiselin (1966) pointed out that some conspicuous characters develop due to specialization and these have less taxonomic value; such characters when taken in phenetic clustering would leave the phenogram far from true phylogeny.

12. Phenetic method fail to take mosaic evolution into account. Because every character has its own evolutionary role. Therefore different similarity estimates will be obtained

when one type of character or the other is used. Phenotypic expression reveals only a very small or often highly biased portion of genotype and there is varying correlation between the two (Rohlf 1963, 1964).

13. Pheneticists do not depend upon plesiomorphic and apomorphic characters. They cannot distinguish a primitive group from an advance group.

(h) *Cladistic Classifiaction*

This theory was proposed by German Entomologist Willi Hennig (1950, 1957) and was initially published in german language. It was not much circulated among scientists till its English translation and revisions (Hennig 1965, 1966, 1975). This was immediately accepted as a standard method of inferring phylogeny. Now there began fall of numerical phenetics.

This concept is based on :

1. Taxa should exclusively be based on synapomorphic characters while ancestral (plesiomorphic) characters are ignored.

2. Every taxon should be monophyletic (= holophyletic) consisting of stem species and all its descendants including all 'ex-groups'.

3. All sister groups should be accorded the same categorical rank.

The worthiness of cladism lies in that it does not rely solely on similarity and it separates apomorphic character from plesiomorphic character.

There is no doubt and any systematist will agree that the revolution in macrotaxonomy was actually initiated by Hennig. His simply structured methodology was immediately exercised on the vast pending field of systematics, which was lying unattended due to many difficulties. Examples are the previously believed unnatural groups, such as turbellarians, many groups of insects, fishes and turtles. After Darwinism, there was a continuous effort to produce a natural classification and perfect theories were proposed (the evolutionary theory of classification). But in practice there was no guideline to determine the genealogy. Cladism provided and explained this procedure from an analysis of the characters of the living forms and this does not depend on availability fossils. Mayr and Ashlock (1991) pointed out that the most important merits of cladism are as follows:

5. Cladism reemphasized that taxa are product of evolution and this is kept in mind during delimitation of taxa.

6. The methodology adopted in cladism is based on careful evaluation of taxon characters and the entire process shows evolutionary history of species.

7. Cladism is first to show how characters could be weighted and separated into plesiomorphic and apomorphic ones. Many previously developed and well-established categories were ascertained by inspection and experiences.

8. Cladistic analysis helps to unmask convergent polyphyly (taxa obtained from different ancestor that undergone convergence and became so similar that they form a separate polyphyletic taxon).

For the above reasons, cladisrn at once gained overall appreciation and it is now practiced by most systematists. According to this theory, the categorical status depends on the position of the branching point on the phylogenetic tree.

It is to be cleared that some authors have mixed. up cladism with phylogenetic classification. Mayr (1969) mentioned that 'Hennig. ...and others have designated themselves misleadingly as the phylogenetic school. .. .' and also stressed that' .... splitting of the branches is only one of several phylogenetic processes .... warned to look out for misleading use of the term phylogeny by cladisrs. Cladism has also been designated as genealogical approach (Gisin 1964)'. Cladists claim to show relationship between members of a group of taxa and they call it '*Cladistics*' or '*Evolutionary systematics*'. In some places even, cladism has been referred to as "*Phylogenetic systematics*". Thus so many names have been applied to the cladism. It should be remembered that original concept has been revised many times in the light of phylogeny and evolution.

Christoffersen (1995) mentioned the differences between cladistics and phylogenetic classification as follows: phylogeny is predominantly bifurcating, asymmetrical and truncate dendrogram whose height increases with passage (increase) of time. But a cladogram is a non-truncate dendrogram with no defined vertical or horizontal axes in relation to time. Cladogram is a graphical model showing speciation points (=branching) and thus an ancestral-descendant sequence but without any explanation of the length of the line or distance between any two line at any given height (angular divergence). Both cladistic and phylogenetic dedrograms show sister group relationship. Horizontal separation, as we know, shows the amount of differences acquired by two taxa.

Deficiencies of cladism

Gradually some aspects of this theory proved to be insufficient and some other needs further research.

1. *Deficiencies in their principle are :*

(i) The categorical rank of a taxon is to be determined by its genealogical age.

(ii) When a species splits, one of the two daughter species tends to deviate more strongly than the other from the common stem species (Hennig 1966).

(iii) Each species in terminated by a split into two daughter species: i.e., all branching points are dichotomous.

(iv) A species begins at a branching point and ends at the next branching point in the cladogram.

Cladists have rejected the first one and the rest three are accepted by some or rejected by others. Farris quantified the contribution of apomorphic characters and thus studied on anagenesis; the results made subsequent modification in cladism (Camin and Sokal 1965), Cladists used some of the traditional terms (e.g. phylogeny, monophyletic, polyphyletic, paraphyletic etc.) in modified sense (Mayr and Ashlock 1991) although this was defended by Wiley (1981).

2. *Homoplasy can put unrelated taxa together.*

Due to convergence, parallelism or reversal of a character may show homoplasy. Such characters confuse the true status of the taxa under study.

3. *Different sets of characters may produce different cladograms.*

Rosen *et al*., (1981) and Holmes (1985) obtained such different cladograms on origin and sister groups analysis of amphibia. By cladistics and using sets of character different from traditional ones. Gardiner (1982) came to conclusion that birds and mammals are sister group taxa.

4. *A branching point not necessarily is dichotomous always.*

Orthodox cladists believe that an ancestral species breaks up into two daughter species. This phenomenon is rare. Mostly parental species remains little changed while it gives rise to one or many lineages in different situations. In case of such simultaneous speciation, a cladogram becomes trichotomous or polytomous. This has been acknowledged by modern cladists (Wiley 1981).

(i) *Variability of a higher taxon cannot be judged if only fewer taxa are analyzed which may not have expressed apomorphy.*

(ii) *Cladism better can compare sister groups, not ancestor-descendant group.*

This is because a species of a holophyletic taxon is more closely related to any other species of that taxon than to any species of an ancestral or sister taxon.

5. *Cladists recognize a holophyletic taxon as a separate taxon and that consists of stem species and all as descendants; its member species share one or more synapomorphic characters.*

But a holophyletic taxon may be very heterogeneous where 'in a lengthy phyletic lineage, the early stem groups are very different from later ones and particularly from the ultimately crown group or because some relatively undifferentiated stem groups give rise to a highly divergent ex-group (e.g. family of turbellarians that gave rise to the parasitic trematodes and cestodes) (Mayr and Ashlock 1991).

6. *Wrong assumption of equal rates of evolution in all phyletic lines.*

The stem species may remain static while the neospecies may show quick changes. Thus there are unequal rates of changes in different phyletic lines which is ignored by cladist.

7. *Wrong theory of ranking.*

According to Hennig's rule for ranking, the product of dichotomy is given the next lower rank from parental taxon and both sister taxa are to be given same rank. This rule will produce far large number of categorical levels than by traditional classification.

8. *Restriction to synapomorphy lead to misuse of information content of many vital characters.*

Traditional classification makes fullest use of most of the characters. Cladists concentrate on only few *synapomorphic* characters and in this way they are ignoring the importance of many vital characters including plesiomorphics, which are part of evolution. 'Systematics in general consists of the search for defining characters of groups' (Nelson and Platnick 1981)'.

9. *Neglect of autatomorphic characters.*

Autaomorphic characters (characters that evolve in only one of the two sister groups) help to analyze the amount of anagenesis and Hennigians thus neglected the anagentic information in the construction of a cladogram.

10. *Cladists excluded fossils from their classification or at best list them as 'plesions'.*

11. *The cladogram may become instable by the introduction of new taxa.*

Such an inclusion makes the holophyletic taxon a paraphyletic. Minor disagreement among the cladists can make a taxon holophyletic by some or paraphyletic by others. This has been found in the classification of agnatha (Halstead 1982) and in Psocoptera, Mallophaga and Anoplura (Boudreaux 1979).

Discussion

In the last several decades some schools emerged to solve the difficulties in the theory and practice of classification which differ in their philosophy. Some deviated from Hennig's rule to varying degree (Hull 1988). Pattern cladists deviated most (Platnick 1979); some retained most of Hennig's principles while Wiley (1981) and others based more on evolutionary taxonomy. Felsenstein (1988) pointed out two major splits: one remained adhered to Hennig's 'phylogenetic systematics' and the other group engaged themselves to computer-based numerical analysis. Edwards, Cavalli-Sforza and Camin and Sokal were developing algorithm based on parsimony and they, along with pheneticists, formed the second group. It is to be noted that some systematists of the second group are not supporter of the cladism although their attempts are based essentially on cladistic techniques.

3.4.6 Comparison of cladistic and evolutionary classification

Cladistic classification	*Evolutionary classification*
A. Synapomorphic characters are used to recognize branching point.	A. Synapomorphic characters are used to discover and reject polyphyly.
B. Parsimony helps to determine best cladogram.	B. Parsimony helps to test homoplasy.
C. A cladogram is constructed.	C. A phylogram is constructed.
D. Taxa are determined by holophyly.	D. Monophyly and maximum number of shared characters determine taxa.
E. As low as single synapomorphic character is needed.	E. Maximum number of shared characters is needed.
F. Sister groups assigned same categorical rank.	F. Sister groups assigned different categorical rank if they differ by sufficient autatomorphy.
G. Ranking depends on diagnostic synapomorphic character.	G. Ranking depends on homologous and ancestral characters.
H. Classification is based on branching of lineage.	H. Classification is based on branching and divergence of lineage.
I. Categorical ranking is arbitrary.	I. Categorical ranking is based on degree of difference.
J. Autapomorphic characters are usually ignored.	J. Autapomorphic characters used in ranking.
K. Stem group is always with crown group.	K. Stem group sometimes with sister group.

Summary

(i) A best classification should be a natural classification.

(ii) Pheneticists believe that 'most similar' organisms are product of evolution and thus show relationship with ancestors.

(iii) Cladists claim to reflect accurately the branching pattern.

(iv) Evolutionary taxonomists claim to adhere to principles of classification and genealogy.

3.4.7 Hierarchy of categories

In a hierarchic classification, each rank (or level) is a category. Categories are designated by such terms as species, genus, family, order etc. Each such category contains one or more taxa and these taxa belong to a given rank. Each such rank is a category.

Category is defined as 'a class whose members are all the taxa that are assigned a given rank'. Thus a genus category contains one or more genera; a species category contains one or more species.

3.4.7.1 Differences between a taxon and category

A taxon refers to concrete zoological objects i.e., groups of organisms, such as sponges, annelids, reptiles, birds etc. Taxon is defined as *'a group of real organisms recognized as a formal unit at any level of a hierarchic classification* (Simpson 1961)'. The definition given by Mayr (1969) is '*a taxon is a named taxonomic group of any rank that is considered sufficiently distinct by taxonomists to be formally recognized and assigned to a definite category'.*

The species name is not a taxon, but the organisms that constitute the species belong to a taxon. A genus name is not a taxon but the organisms that are the members of that genus together given a higher taxon name. A taxon name is usually a common word, not a scientific abstract term to describe a particular group of animals. When we say insect (a taxon), we know what is an insect and also know that there are many orders and families of insects; when we say butterfly we at once recognize a butterfly (a taxon of lower rank than insect). In these examples, the insect belongs to class Insecta (a higher category) and the butterfly belongs to order Lepidoptera (a lower category in respect to class category, but a higher category in respect to genus or other categories below order rank). We can define a species or a genus. But we cannot define, say a butterfly, but can describe the butterfly. So taxon is a thing (zoological object) that can be described and not defined.

'*A higher taxon is an aggregate of related species separated from others by a discontinuity'* (Mayr 1969). The lowest taxon is at the species level and all taxa above species rank are higher taxa. This definition is not suitable for monotypic taxa whose members are all alike; e.g., if members belong to one species or if members belong to one genus. Such a monotypic higher taxon is separated from the next one higher taxon by all lot of differences.

Higher categories

A category is an abstract term, the name of a class. Higher categories are not perfectly delimited. Specialists have often ranked a taxon higher which other scientist ranked lower. For this arbitrariness, higher category differs from the species category.

3.4.7.2 Hierarchy

Aristotle's *Scala Naturae* predominated for over two thousand years and his theory profoundly made scientists to believe that all animals are arranged from 'most primitive' to 'most perfect'. Thus animals were thought to undergo a continuous change and at any time, all animals are members of same class (types). Linnaeus was a follower of Aristotle; he framed higher categories but could not explain the significance of a hierarchy in the light of *Scala Naturae*. Their explanation was that a higher category splits into lower categories. This was just reverse to what emerged in post-Darwin era.

Darwin saw the organic diversity as a result of speciation; the gradual evolution of higher and higher taxa separated by gaps was by chance and adaptive processes and these were the cause for divergent evolution. Therefore speciation, adaptive divergence and extinction are reflected in a best hierarchy. He clearly explained the fundamental principles as: ' the natural system is genealogical in its arrangement, like a pedigree; but the degrees of modification which the different groups have undergone have to be expressed by ranking them under different so called genera, subfamilies, families, sections, orders, classes'. Thus higher categories evolve through evolution; not that higher categories subdivide to produce lower orders.

Species has no subordinate category and thus it is the lowest category. As a genus consists of one or more species, a family consists of one or more genera. Here genus and family both are higher categories. In this way all organisms are placed or ranked according to their comprehensiveness, in a hierarchy of categories, which is commonly known as *Linnaean hierarchy*.

Linnaeus recognized five categories and these are *classis, ordo, genus, species* and *varietas*. The variety (= *varietas*) was used to designate infraspecific variations when present i.e., it was optional. This was discarded or replaced by the category subspecies. Two more categories soon developed, the family (Butschli 1790) and phylum (Haekel 1886). With the addition of kingdom, there became seven categories and any organism belongs to these seven categories. Hence these seven categories are known as obligatory categories (variety is excluded, as it is optional). These are kingdom, phylum, class, order, family, genus and species. All living organisms belong to five kingdoms, protista, monera, fungi, plantae and animalia. Linnaean hierarchy consists of a nested set of taxa of different categorical ranks. A number of taxa of any rank are closely related because of their common ancestor. However degree of differences increases among the members with the higher rank. More similarity is observed among members of taxa of very lower rank. Because the common ancestor in the previous case is far (*i.e.*, more separated in time and with greater variation in genotypes); in latter case, the common ancestor is very recent.

Merit of Linnaean hierarchy

The merit of Linnaean hierarchy is its flexibility. More and more newer categories can be included as more organisms are dealt in future. It is thus provisional, allowing taxonomists to store greatest information by splitting or lumping of categories and thereby presenting best hierarchy. It was once proposed to assign specific numerical values for categories. This was rejected for two reasons: one, assignment of value need far greater knowledge about their relationship based on 'all species on earth' and two, assignment of value will freeze the number of categories and the hierarch will loose its flexibility.

Based on the scrutiny of the classifications done by taxonomists, Mayr (1969) found that they recognize taxa on the relative merits of five considerations:

1. Distinctness (size of gap).
2. Evolutionary role (uniqueness of the adaptive zones).
3. Degree of differences.
4. Size of the taxon.
5. Equivalence of ranking in related taxa.

3.4.7.3 Additional categories

Since Darwin's publication, there began active search for newer species throughout the globe and scientists were more interested to draw relationship and evolutionary mechanism. The result was the growing uneasiness to rank known species into those fixed seven categories. In other words, due to immense pressure to rank them all and due to the presence of so many distinctive groups that the number of existing categories were increased by splitting them. The additional categories were mostly designated by adding prefixes as " super"(above an existing category) and "sub" (below that category). Thus we have superfamily, subfamily and others. However there are no categories as superphylum, supergenus or superspecies.

Two more category names were added to the hierarchy. These are "tribe"(below subfamily) in entomology and "cohort"(below subclass) in vertebrate paleontology.

Categories from superfamily to tribe are formed by adding suffixes: "-oidea" for superfamily, "-idae" for family, "-inae" for subfamily and "-ini" for tribe. Such standardized term are not available for categories above the family rank. An example is given below:

Superorder Blattopteroidea, Order Mantodea, Family Mantidae, Subfamily Mantinae and Tribe Mantini.

3.5 Taxonomic characters-different kinds, origin of reproductive isolation-biological mechanism of genetic incompatibilities

3.5.1 Taxonomic characters-different kinds

Mayr defined taxonomic character as '.. any attribute of a member of a taxon by which it differs or may differ from a member of a different taxon". Taxonomic characters are the characters of a population and not the individual differences in age, sex and such others. When two populations differ by presence or absence of a character, then that becomes a taxonomic character. Thus the character must show potential or diagnostic feature of a taxon. Therefore the taxonomic character of a taxon reveals relationship between itself and other taxa and those characters help in the study of higher taxa. The diagnostic features are strong at the level of lower categories by which the taxa is specified.

Out of many taxonomic characters, some are chosen for comparative study. These characters, as an experienced taxonomist feels, have more information content and reveal relationship in a better way. A taxonomic character may not be a phenotypic expression. Any such expression is ultimate product of complex gene interaction. Till to day, genotype of most taxon remained unsolved and not all genotypic variations are good taxonomic character. Again not all phenotypes exhibit real information all the time. Adaptation to one environment by unrelated taxa will produce lots of characters, which are redundant for the phylogenetic study.

So long potential characters are not identified, a taxonomist searches for all available characters and thus gives equal weight to all characters, he or she will be misled. Because this procedure will conceal the effects of convergent or parallel evolution.

An unreliable character has low weight and examples are those characters which vary quite frequently. For example the branching of the arteries varies in the members of a species population. While wing venation is an important taxonomic character in some group of insects, it varies widely in some others thereby looses its taxonomic importance.

Some characters show gradual decline in its shape, size or function. Examples are the shortening of wing, loss of eye etc. These regressive characters have low weight.

Both identification and classification depends on analysis of characters. Some characters are used in both the cases, but very few and selective characters are required in identification works. Identification at species level depends on easily available (chiefly morphological) characters and such identification can even be done on specimens long preserved in museums and are always available to future scientists. Such specimens will not be useful in any further biochemical, physiological and such other works that demand live one. Although we know that any experimental analysis related results are useful for systematic work, these are not much useful in identification or other methods to be undertaken are complex.

Significance of characters :

Besides temporary characters (such as seasonal, sexual or those which are variable characters), all organisms evolve certain configurations or characters, which is therefore, outcome of long history of manipulations under various thresholds of environmental influences. Added to this are the natural mutations, hybridization and intrinsic phenomena, which drive those changes. We should not forget that instant, temporary or seasonal characters have a past history and they serve good purpose in species identification.

Field study of organisms clearly shows many diagnostic features of an organism. Actually the ecosystem moulds an organism inhabiting to its specific nature. Such as darkness makes all organisms uniformly colourless or animals in the arctic region becomes white to match the surrounding. Tropical organisms are variously coloured. Organisms show development of similar characters due to convergence, but the organs are analogous. Related sympatric species develop stronger morphological differences to get rid of accidental hybridization and competitive exclusion. This process was termed as Character displacement by Brown and Wilson (1956).

Taxonomists looked upon speciation by isolation as a curious phenomenon to which the definition of species is related. At a given time the separation of two taxa is based on their separation so as to prevent hybridization. This is accompanied with development of contrasting characters observed in their reproduction strategies.. They have passed through many generations and natural selection to achieve this goal. It is not certain that all the present species on the earth are those best selected form. Rather all organisms are still changing or evolving along with the nature and many today will be proved to be less fit in future or in the present situation of the ecosystem. Natural hybrids are formed in genotypically closely related species and some of them may show better fitness to at least in present scenario.

The entire above situation expressed in the form of characters are valuable in taxonomic study. Stable characters are conservative and are of high weight. These are important in tracing of ancestral history of a species and in the construction of phylogeny.

Taxonomists may often ignore many, perhaps minute characters. This is because having sufficient characters at hand and probably completed a systematic work; he or she may willfully avoid those characters as unwanted. This will create lot of problems in future study and surely lead to a wrong conclusion about the lineage. Any character, whether minute or big, is the outcome of functional genes. All characters interact with the environment and we are ignorant about each such phenomenon. A study of members of a species over a wide range show how the characters are associated or adapted to their respective ecosystem.

Morphological characters are the product of a part of the genome and not of the entire genome. So genetic relationship is not fully expressed by these characters. Therefore, taxonomist now deal with many other types of characters including the studies of biomolecules (proteins, nucleic acids) and correlation of these biomolecules with the phenotypic expressions. This wider range of viewing a species is the essence of *New Systematics*. This vision has solved many confusing problems in typical morphotaxonomy. Although this approach is still very young, it has actually strengthened the evolutionary classification that was actually established on the basis of classical approach.

Kinds of taxonomic characters :

Mayr (1969) has categorized these characters under five heads, each with their further subdivisions as follows.

1. Morphological characters :

The external features and often anatomy of living or museum specimens provide most of the important taxonomic characters of a species. There are many internationally famous museums and research institutes, which preserves the history of organic evolution. They also periodically publish the status of their materials, new additions, condition of them and such related events. Research articles on these materials are also available from their library. For microscopic organisms, external characters include anything visible under microscopes of different kind up to any resolution as needed. Surface texture or surface structures or derivatives e.g. test, shell, theca, warts, epidermal structures such as scales, feathers, hair and variation of all these and other prominent features are studied in cases of larger animals. Morphology of sperm has received attention in identification of a species as a key to species isolation. Study of specialized cells (by histology, histochemistry, TEM) is routine work in understanding the functional aspects of an organ.

Colour pattern is nearly specific and easily available morphological character. But there are many colours which are seasonal or develop temporarily in response to environment (including prey-predator relationship, courtship etc.). Some colours are specific and permanent as those of many insects, birds, and many other organisms. They serve to identify them easily. Colour is lost in long preserved museum specimens and later does not match with originally published account. Polymorphism or gradation of character (colour) is common in a population of some species. Variable colour should be examined and judged carefully.

Much attention has been paid to the structure of genitalia for interspecific distinction and sometimes this character has been used in separation of higher taxa. By definition of a species, this will differ in closely related species. Problem arises in cases of similar (but not identical) structure of genitalia as to whether they belong to same species. Actually the amount of difference needed for separation of a species is not available. This is the reason why some natural hybrids are found in nature. In the absence of proper mate of own species or similarity in mating behaviour often brings about such event. Reproductive isolation in nature can not be proved so easily in such case. Many cases of gradation of variation in genitalic complex is known in insects and other groups. However the genitalia morphology is very strong tool to distinguish morphologically alike unrelated species in most cases. Genitalia are carefully dissected out, preserved in proper medium for future reference.

Task of obtaining characters are now easier by innovation of instruments and techniques. The results is the accumulation of heaps of raw data. Unfortunately little of these have been summarized to be utilized in the study of the evolution of the group. However stray works on some groups are available and until all of a family or higher taxon is done, the systematic work will remain pending.

Usually vertebrates being highly evolved have developed characters, which show more constancy, conservativeness and are less fluctuating. These are easy to handle because they are more distinct and highly dependable. Measurements of whole organism or parts, dissection of formaline preserved material for anatomical studies on the comparison of soft parts or organs, or bones are important in understanding the line of descent and modifications. A vital part like a skull with jaws and teeth can tell many taxonomic characters.

2. Developmental characters :

Characters shown by developmental stages and their adults have been used as good taxonomic characters in some groups. Embryological features are used in the taxonomy of sponges where adults are very similar (Le´vi, 1956). For example. Sibling species of

Anopheles maculipennis are classified on the basis of egg morphology and in white flies (Aleyrodidae) identification is principally based on pupal differences. It was noticed that many taxonomic characters are distorted due to adaptation at any stage of life. As in digger wasp (Sphecidae) Evans (1964) has shown that certain adult structures were paid high weightage and that has improved taxonomy of the group based on larval characters. In frogs, studies were made on the larvae and their characters were judged with that of adults for perfect analysis (Orton, 1957; Igner, 1967).

3. Chromosomal characters :

Karyotype study is easier in groups like Diptera and Orthoptera where the chromosomes are bigger and fewer in number. In most organisms this is just the reverse and therefore, difficult to analyse in Lepidoptera and birds. Characteristics of chromosomes usually differ in related species and a complete data of a group help in phylogenetic analysis of a group. Intersetingly the changes in the characteristics of a chromosome is not always reflected in phenotypes and this one reason that many sibling species identification is based on karyotype studies. On the othet hand, related species show considerable rearrangement while some species are polymorphic due to chromosomal rearrangements.

From phylogenetic angle, any form of chromosomal change being a permanent event is seen in descendants and is used as a marker in identifying a phyletic line. Polyploidy (a rare event in animals), aneuploidy or structural changes in chromosomes (such as deletion, duplication, insertion etc.) are all important taxonomic characters and, now-a-days, specialized techniques help to identify them. Innumerable data are now available in this subject.

Chromosomal matching percentage between two taxa is long used as a measure their taxonomic distance. But there is no specific value to this because the percentage differ widely in different groups. In spite of many exceptions, rate of production of viable and fertile offspring obtained by hybridization of interspecific (or sometimes intergeneric) is a good measure of taxonomic relatedness between two taxa. Because post-zygotic isolation acts at many stages as a result of mismatch in protein syntehesis by deformed functional genes. Duck shows wide range of interspecific or even intergeneric fertility although there are examples of exception to this (hybrids of *Aix sponsa* and *A. galericulata* is sterile). Evolutionary significance is not clear why some groups of birds show fertility while some insects show sterility in related interspecific hybridization. For this reason Blair(1963) studied this comptibility in hybridization in *Bufo* and rearranged the species.

4. Physiological characters :

Probably all physiological characters are only studied in living animals. Taxonomists who rely on museum specimens (for comparative studies) can not get physiological data, such as effect of abiotic factors, enzyme system and others. Lots of work have been done to understand physiological variation among taxa to reflect correlation with the environment. These data between species show certain differences and can be treated as characters of a species. Plants and animals continually or discontinuously produce certain metabolites to the exterior and these are specific for an organism. Genic sterility is a physiological phenomenon but this is more discussed as chromosomal event.

5. Biochemical characters :

Major biochemical pathways are nearly uniform in all the evolved taxa. Still there are very much specificity in many biochemical reactions in all organisms. Such specificity even exists within the members of a species population (e.g. blood transfusion in human). Taxonomists widely used immunology as efficient method to determine closeness between species although there are many shortcomings of these methods. Identification of proteins, nucleic acids and their sequencing are going on some taxa to identify closeness of taxa, which are again not totally free from various technical difficulties. But such studies at finer level create critical situations. Gross analysis of vital protein, enzymes or DNA hybridization are easier to handle and are frequently used in taxonomy. One such widely studied is the hemoglobin of primates and man show that African Apes (*Pan*) and man (*Homo*) show very little changes in hemoglobin and serum since their separation from common ancestor although their adaptive zones are very widely different.

6. Ecological character :

Every species has its own specific niche in an environment and thus displays good taxonomic character for separation of very close relatives. These factors are period of activity, habitat, food selection, breeding period and others. These are so vital that morphologically alike so-called same species living on different plants were proved to be different species. Host differences do not always mean separate species. Mayr (1969) has shown that peripheral population of a species shows differences in ecology as a local population. And thus subspecies shows distinctions. Among many examples of ecological separation that of Galapagos finches and *Anopheles maculipennis* complex are well illustrated examples.

7. Parasitism as a character :

Host parasitic interaction is a result of co-evolution and often shows characteristic pattern that help in species identification. Although parasites normally invade any unexplored host, but they mostly show constancy in host selection. Probably they fail to survive in unlikely host and sometimes a parasite shows closer affinity to related taxa. Parasites with wider adaptation can be found in unrelated taxa (e.g. bird lice, Mallophaga on geese). Many intestinal protozoans are useful indicator of relationship among termites

(Kirby, 1950b). Intracellular symbionts are absent in primitive tribes of coccids but they are present in some descendants (Buchner, 1966a). So under careful studies, many such observations can halp to indicate phylogeny of an organism.

8. Ethological characters :

Similar to niche separation, every species shows distinct behaviour (except mimicry and such adaptations). Besides morphotaxonomy and cytotaxonomy, ethology is an interesting and widely investigated area in biology. It provides lots of highly informative characters which are genetically imprinted in any species. These are diverse such as mate selection, courtship, nest building, predation or prey capture, mating call or songs of different meanings. Classification of many insects, fishes, amphibians, birds and others were refined on the basis of ethological data.. Among many data, some are those of digger wasp (Evans, 1957, 1966), sweet bees (Sakagami and Michener, 1962), gulls (Tinbergen, 1959 and Moynihan, 1959), North-American crickets (Walker, 1964). Sibling species of frogs and toads were clearly identified from their different calls (Littlejohn, Main, Mecham and others). Many bird calls have been recorded and the copies are available to match with a given a specimen in nature for easy identification.

9. Geographical character :

It is expected that all descendants of an ancestor will inhabit same broad geographical area. A perfect classification shows a relationship with the distribution (habitat) of an organism. Any variation in the organization will also be related to the changes in the of pattern distribution. This is true as a descendant with some vital modification or acquisition of characters to suit that environment occupies the new adaptive zones. Each geographical area has its history of development (geological history) and this is meaningfully associated with its own animal evolution. Therefore the adaptive characters of an organism tell many features of its habitat and its distribution shows the range of habitat. The range is usually distinct although may be inhabited by many related or unrelated taxa in the same area are not uncommon.

3.5.2 Origin of reproductive isolation

Natural species are kept as true species in nature by means of diverse mechanisms that isolates them from other species. Although some amount of hybridization occurs in nature they are supposed to face many hindrances to become successful species. Still some exceptions are there and they will be discussed.

New species are formed from an existing species when some factors isolate some members of the parental stock in such a way that in the long run, they fail to interbreed with the parental members. Wagner and Darwin emphasized its importance in the evolution of animals. Later on Mendelian genetics confirmed this route of evolution. Newman suggested that evolution couldn't be explained without the role of isolation.

The isolating mechanisms are of various nature and strength. Chiefly they are ethological, ecological and hybrid sterility. These are important in maintaining the genotypic identity of a species.

The origin of the reproductive isolation, according to one view is an accidental by-product of genetic divergence. Different populations, in course of time, become more and more dissimilar in their genetic identities. The other proposition by Wallace and supported by many modern evolutionists is that reproductive isolation is a gift of natural selection. Since the hybrids are less fit and have less adaptive capacities, they will be gradually eliminated. While the true species, which are already adapted to ecosystem will produce more successful generations.

3.5.2.1 Theories on the origin of reproductive isolation

Two theories were proposed to explain the origin of reproductive isolation.

1. The theory of Muller states that the members of a parent species may inhabit various geographical regions and gradually become adapted to newer ecosystem. Dispersal of species is a common affair and due to various reasons the dispersed groups occupy newer niches. This separation over a long period causes accumulation of genetic differences from parental stock to such a degree that there is origin of subspecies and species in those allopatric populations. Therefore reproductive isolation is an incidental by-product of genetic divergence.

2. The second theory proposed by Wallace (1889) and later supported and explained by Dobzhansky states that reproductive isolation is an outcome of natural selection. This theory is based on prevention of hybridization in nature. In other words, the natural selection has formed a barrier between species and prevents unwanted mating. This type of reproductive isolation operates after accidental hybridization. The hybrids are generally non-viable and are gradually eliminated from environment and reduce wastes of gametes.

3.5.2.2 Evolutionary origin of reproductive isolation or Genetic basis of origin of reproductive isolation

In nature, the hybrids formed show various degrees of success. However the progeny does not proceed further and is eliminated by natural selection. Species 'a' species 'b' cannot be considered as distinct species only if they produce sterile hybrids. This is because, as explained earlier, hybridization may occur in nature and shows various degrees of success. Many species frequently hybridize in artificial conditions.

The importance of prevention of hybridization is that each species has its own gene pool, which has been tested by natural selection and exclusively matches the environment. It has many deleterious genes, which are rare in expression. But a hybrid or break up of barriers between other two or more gene pools will expose innumerable genes, which will be of very low in success or highly or partially lethal to offspring. There lies the need for separation of gene pool.

According to Mayr (1942) and Sibley (1957), some species-specific characters functions to prevent unwanted reproduction. These characters are favoured more and more by natural selection and become exceedingly conspicuous. The species of birds without pair formation is an example of such character development.

The production of new genotypes is actually exploration by the species and may or may not found an unoccupied adaptive niches. The result may be a success with varying degrees or may be a total loss. Thus newer combination is simply a luck try. This results in huge loss of progeny, which even can cost to extinction of the species. However the parental gene pool, which is firmly adapted to present environment, continues at normal rate. Only few successful newer variants may pave the way to revolution through hazards of natural selection.

Recombination of genotypes of distinct species sometimes presents offspring, which are equally, or more fit to the environment of the parental stock. Such variants emerge out of introgresive hybridization, allopolyploidy and recombination and all these have effective role in evolution. However there are occasional hybrid breakdown in nature.

The three most important factors in evolution are isolation, adaptation and variation. Mutation helps in evolution but is not considered as a basic factor. Isolation is achieved when any external or internal factor prevents interbreeding. Isolation is the phenomenon of separating a population into two or more sub-populations through prevention of interbreeding.

The male and female gametes unite to give rise to a new offspring. These gametes may come from a male and a female partner or from same individual (hermaphrodite). There are a variety of mechanisms in unicellular forms including bacteria. However many unisexuals prevent self-fertilization through different mechanisms; in others the self-fertilization is the only means of propagation of the race.

The zygote receives a recombination of parental chromosomes. Enormous gene combinations are possible through meiosis and recombination. Therefore the new generation offspring with newer genotypes are now subjected to natural selection. The prevalent environmental conditions may be favorable or unfavorable to them. Even some genotypes may be proved to be better preadapted to a future condition. Some new genotypes may try to establish to the present situation at the cost of huge loss of offspring. They may achieve success and some may endanger the perpetuation of the species during the loss of excessive number of offspring in the battle for survival.

3.5.3 Biological mechanisms of genetic incompatibilities

According to Mayr, sympatric species maintain its identity of gene pool by the following types of isolating mechanisms:

(a) Prevention of mating by potential mates by restricting random dispersal.

(b) Prevention of mating by some ethological, structural or other mechanisms by which potential mates are not allowed to meet.

(c) Hybrid steriIity and reduction of fertility.

According to Dobzhan'sky the isolation of sympatric species is achieved by geographical or permanent separation.

3.5.3.1 Prezygotic and postmating (zygotic) isolation

Species is defined as a Mendelian population between which there is no or very little genetic exchange is possible. The isolating mechanisms which operate among species may be premating (prezygotic) or postmating (zygotic).

Premating (prezygotic) isolation ways

1. Habitat isolation : This isolation is an outcome of continued adaptation of a population to its biotic and abiotic nature of the environment. Thus it is governed by soil profile and geography, climate and all those exert direct and indirect effects on vegetation and population. Within an apparently homogeneous environment, there are many minor differences in its biotic environment (such as differences in salinity, light, pH, oxygen, nutrient etc.). These are, therefore, act as barrier to smaller animals.

It should be noted that in areas of hybridization of two subspecies, the hybrids show characters of both subspecies. Since all the members of the subspecies and the hybrids are actually the members of one species population, we should not use the term 'overlap' of the subspecies. The term subspecies has been used and defined differently by many authors and created lots of trouble. If used in proper sense, the category subspecies has much usefulness to population taxonomists.

Distance becomes a barrier to many invertebrates and several vertebrates. Therefore dispersed and isolated population may not be able to return to home stock and will eventually evolve separately. Newer areas exert newer adaptations which changes gene frequency in those forwarding group. Mammals radiated from 'Holarctica' (Northern Asia, Northern Europe and North America) and undergone spatial isolation to give rise to many new taxa even in the absence of distinct barrier.

The partial barriers those permit migration and interbreeding give rise to progeny with almost homogeneous basic features. But the members show minute differences and continue to adapt to partially differentiated habitats. Such incompleteness of barriers produces diversity in species population. Such a situation continues till the formation of a perfect barrier, which actually isolates the populations on either side of that barrier. By this time the populations have accumulated newer alleles and therefore gene combination becomes different from the parental population.

Different species may inhabit same area but different ecological habitats and hence ecologically isolated. The *Anopheles maculipennis* group consisting of six species is a good example of sibling species. They are morphologically similar but genetically and reproductively isolated good species and occur in different geographical areas. The species show distinct differences in the selection of breeding sites, courtship, transmission of pathogen, egg-float characters and many others.

2. Seasonal or temporal isolation : Different species exhibit sexual maturity or become competent to mate or reproduce at different time and thus seasonally or temporally isolated. This is very common in plants. An interesting study (Blair, 1941; Cory and Manion, 1955) on *Bufo americanas and Bufo fowleri* shows that the two species become sexually mature at different periods of the year and reproduce at those specific seasons of the year. However, since a particular period overlaps between their separate reproductive seasons, some amount of hybrid offspring are also produced in some man made artificial habitats. Pulmonates are hermaphrodite and are known to mate for mutual insemination. There are different phases in a successful fertilization and production of viable offspring. These are search for suitable mate, courtship and transfer of gametes. Each of the steps play crucial role in a species and are highly species specific which all are to prevent hybridization in nature. Experimental keeping of females of *Drosophila pseudoobscura* and *D. persimilis* in same container along with the only the males of *D. persimilis* produced 79.2% of *D. persimilis* and 22.5% of *D. pseudoobscura.* The cue to such species selection may lie in their various tactile senses and pheromones. Littlejohn (1965) have demonstrated that auditory signals of frogs and toads are species-specific.

3. Mechanical isolation : This is due to different shapes or structures of genitalia of different species. This is, hence, a good taxonomic character. Entomologist Dufour (1844) proposed lock-and-key theory of selection of species, which is based on structure of genitalia. However it is true that many different species with structural variation in genitalia mate well to produce successful progeny. However there are instances of injury and death in such attempts.

4. Chemical isolation : The structure and or chemical nature of surface of gametes of many species are so different that they only attract and unite with conspecific ones.

5. Ethological isolation : The different species inhabiting very close to each other do not mate because they do not have any attraction to opposite sex of a different species and thus an ethological isolation works.

6. Gametic mortality : It was observed by Patterson in case of *Drosophila* where the sperms were unable to withstand the physiological conditions (pH, temperature, salinity and others) in the female tract and the wall of the latter swelled and finally the sperms die.

Post-zygotic isolation

These mechanisms are classified into three broad categories- hybrid inviability, hybrid sterility and hybrid breakdown.

(a) Hybrid inviability

This happens from the starting point of the zygote formation upto various stages in the life of the hybrid. It is better for a species to avoid anything that will decrease its fitness. If any hybrid in nature becomes unsuccessful it is better not to produce them to avoid loss by fitness. The best way to avoid this is prezygotic isolation. However, in nature, occasional hybrids are produced having varying degrees of success. There are different stages where the life of the hybrid is culminated. Mostly the embryos do not proceed beyond the two to three cell division stages. The reasons may be the dissimilarities in the genetical, biochemical or physiological properties of the embryo or the environment associated with its development. Sonneborn observed the phenomenon in *Paramoecium aurelia* group where the embryos continue development for some stage and then die away. Embryos that cross above stage of development suffer from malformation and eventual death.

Moore observed differential inviability in 12 species of *Rana* and confirmed that in some cleavage stopped, in some no gastrulation occurred while in others later stages did not flourished. Hybrids of *Ranunculus millanii* and *R. dissoctifolius* (this two belong to different soil and climate conditions) do survive only in intermediate habitat caused by man. In plants Clausen 1951, Stebbins 1950 and others observed similar situation. The hybrids obtained by interspecific crosses of *Datura* cannot proceed beyond eight-cell stage.

(b) Hybrid sterility

The hybrids may be partially or completely sterile. The sterility arises due to chromosomal or genic dissimilarities. The sex organs of such hybrids normally continue the process of production of gametes up to premeiotic stage but suffer unsuccessful pairing of parental sets of chromosomes at meiosis. Grant (1981) observed that chromosomes of such hybrids suffered multiple translocation; many gametes are aneuploid (deficiency in proper number chromosomes) or deficient of portions of specific chromosomes). Karpechenko (1927) found that sterile the hybrid obtained from *Raphanus* and *Brassica* produce gametes bearing 6-12 varying number of chromosomes and hence no viable pollen or ovule is formed. However, the allotetraploid (*Raphanobrassica* with 18+18 chomosome number) obtained from unreduced gametes produce viable pollen and ovule. Clearly this sterility is due to difference in partner chromosomes that could not be matched. This mismatch was rectified in allotetraploid. Similar observation was found in *Primula verticillata* and *P. floribunda*.

Hybrids obtained from *D. Pseudoobscura* and *D. persimilis* show abnormal cell division producing some bivalents with full numbers of chromosomes (in primary spermatocyte) or some chromosomes may remain unpaired. But some female hybrids can successfully be backcrossed to male of any parental species. The reason of such genic sterility lies in abnormality during development by uncoordinated behaviour of gene complements during germ cell (but not somatic cell) formation.

Genic sterility is more common in animals than in plants. While chromosomal sterility exerts its effect at or after meiosis, the genic sterility act as isolating factor before, after or at any stage of meiosis. Some hybrid sterility proved to be due to combined effect of both gene and chromosomal abnormality.

Sterile hybrids sometimes show vigorous somatic growth and mule (hybrid of donkey and female horse, each with 33 chromosomes) is the best example. This is due to dissatisfied pairing of genes or cytoplasm of different sources.

(c) Hybrid breakdown

Hybrids very often fail to perpetuate because they fail to exchange gene with any species population. Occasionally they fail to reproduce after second generation or during backcross with a parent. In both cases the progeny contain genotypes of low fitness and are weak; many are sterile. Artificial insemination of female cattle by semen of sterile hybrid buffalo (obtained by crossing American bison and beef cattle) was done. This backcrossed hybrid was fertile and this buffalo propagated themselves.

D. *persimilis* and *D. pseudoobscura* show habitat difference. The former is active in the morning period and latter is active in the evening of the day although the range of their distribution overlaps in large part of the Western United States. Thus it is more probable that both hybrid breakdown and differences in ethology act to isolate the two species.

Hybrid breakdown was also observed in plants (*Gossipium baradense, G. tomentosum* and *G. hirsutum*, (Stephens 1950).

3.5.4 Discussion

3.5.4.1 Isolation, inbreeding and selection

Isolation of animals is related to habitat isolation achieved by various natural phenomena. Among many such events some are submergence or rising of land mass, desertification, permanent snow fall, change of course of water body and tectonic movement. Change of vegetation is often correlated to these events. However, newly developing land mass gradually acquire both vegetation by various natural passive or active methods.

So far best studied isolation is those on oceanic islands although the pattern of speciation may differ from that in mainland. The fauna and flora on Galapagos and Hawaiian Islands are probably the best studied speciation in isolation. Studies reveal that taxa present on continents or on islands once connected to those continents, are absent on oceanic islands which were never part of the continents. Rather some taxa are quite diverse in later islands. The reason might be that the species accidentally reached the islands and enjoyed previously unoccupied niches. Usually absence of competetor, predator and unlimited resource enable a founder species to flourish at a rate higher than that possible on mainland. The descendants of an ancestral species probably from nearby continent migrated or were carried accidentally to such oceanic island and undergone speciation at a quicker pace. In that case, the number of species will be more on such island than on continent. This was the probable cause of the occurrence of fourteen species of Darwin's finches in comparison to only six species of all other passerine and single species of cuckoo are now present on Galapagos. The finches arrived first and enjoyed time and space for diversification. Similarly the hundreds of species of *Drosophila* in Hawaiian Island Archipelago are descendants of one or two ancestral species.

In almost all cases, speciation on oceanic island is very rapid and diverse. The founder species takes a small fraction of ancestral gene pool of a nearby continent in most probability. Since in a new niche, there is no immediate occasion of genetic variability, there will be inbreeding for many generations. Any isolated group with fewer members will continue to increase in number by inbreeding. This small gene pool will gradually develop more homozygosity and express lethal and deleterious genes. The result is a severe loss of fitness. It happens that high rate of production allows high rate of recombination of ancestral gene pool and each offspring gets equal chance of survival in a homogeneous environment free from all fear of competition or predation. Many of these are very similar and few develop certain new combinations that are bit advanced in the new environment of this island. There are obviously many differences in flora of such island from a continent. So the newer progeny may find it suitable or unsuitable. Those able to adjust will radiate better than others and those others seek other habitat in that geographical area. Each generation multiplies probably geometrically to occupy more resource resulting to varied adaptations through dispersal. The new population shows rapid change in its initial genetic combination, which adds to species formation.

Besides the chance of recombination at higher rate, genetic drift is a very important mechanism of speciation. Mutations that increase reproductive fitness will be preserved by natural selection and will increase in frequency thus changing the genetic combination of the founder group. Natural selection keeps the frequency of deletrious allele at lower frequency by elimination.

Formation of separate geographical locality by isolation of a landmass from a continent the population in a different way. The separated population takes a higher amount of ancestral gene pool and has better chance of recombination. But due to the existence of all features of parental habitat, the changes in gene frequency is almost as normal as that of the ancestral home. Therefore, speciation is not rapid if there is no exceptional change in climate. Tectonic movement produces change in the climate of a land mass and hence the populations are subjected to a gradually changing environment. Since the phenomenon is slow, the speciation will be slower. Once separated, the organisms will thereafter evolve separately chiefly due to differences in climate along with changes in flora. Such an isolated mass may act as filter-bridge or other form so that this may be inaccessible to most while accessible to few forms. Therefore diversity in such island depends upon its own history.

3.5.4.2 Introgressive hybridization

According to Anderson, 'introgressive hybridization' is the phenomenon of backcross between a new hybrid and parental species whereby some parental genes will 'introgress' or included in genotype of the hybrid. Anderson opined that introgressive hybridization is useful for hybrid survival. The necessesity lies in the fact that any hybrid, due to the presence of combined genotype in them, will prefer a habitat intermediate to the different parents. This means almost something like 'hybridization of habitat' and such habitat dose not occur naturally. We find that man has created many unnatural habitat and these can easily be taken up by such hybrids formed through easy exchange of genes between related populations.

However, not much work on introgressive hybridization has been done with animals. Studies of Anderson and Heiser on plants proved that such events take place in nature in enough number. Backcrossed individuals were found to be so much effective that they produce 'hybrid swarms'. An example cited by Heiser on sunflower revealed that *Helianthus annuus* and *H. bolanderi* are believed to be originally inhabitant of eastern and western coast of United States and thus ecologically well separated. Their natural hybrids are found in many disturbed ecosystems and actually produced hybrids swarms. Such a hybrid swarm develop by segregation of hybrids in first, second or later generations. Such segregated populations are in the meantime may be mixed up with the backcrossed progeny. The total result is the production of numerous gene combinations along with varying degrees of fertility and viability excepting only backcrossed progeny.

3.5.4.3 Failure of isolating mechanism

Often due to natural or unnatural reasons, the barriers responsible for isolation and speciation may be withdrawn or removed or lost. In some cases indirect barriers to isolation may be lost. The result is mixing of previously allopatric species to become sympatric. Such new population shows different features in course of time.

Studies on birds of Central Europe by Mayr show the origin of sympatric species of birds. During Pleistocene glaciation Scandinavian and Alpine ice caps approached each other in central Europe, which separated the originally inhabiting temperate fauna and flora into Southern France and Spain in one hand, and Balkans at the other, i.e. at the opposite ends of Mediterranean Sea. Again, with the recession of the ice cap, the two segments, now already well speciated came to occupy the parental habitat. The result of such previously isolated and now co-existing populations are many.

(a) The two populations may accumulate such genetic differences that they remained as a good separate species in the sympatric population.

(b) There is rare hybridization of two once separated populations; the example is those of hedgehogs, *Erinaceus europaeus* and *E. roumanicus*.

(c) The hybrids of two stable species of crow *Corvus corone* and *C. cornix* are observed in the transitional areas between eastern and western habitats. This are the examples of polytypic species (also earlier termed as rassenkreis (Rensch) and formenkreis (Lorenz, Kleinschmidt)

3.5.4.4 Some remark on isolation

Experiments on the number of gene differences to produce hybrid inviability shows that a single gene in plant *Crepis tectorium* is lethal enough to produce the effect. This gene, however, has no visible effect in that species. It is assumed that at least two genes are required for reproductive isolation and instead of acting as post-mating barrier, may be eliminated by natural selection; thus enhancing the chances of occasional hybrids in nature.

The effects of natural selection become greater and greater on species that acquired post-mating isolation. This helps to reduce the loss of fitness from inter-specific mating. Another effect is the feedback enhancement of pre-mating isolation.

Observation by Littlejohn (1965) proved that phenotypic or behavioural similarities exist among different species, which are allopatric. The same species will show differences of characters where they are sympatric. Example is the similar mating calls of *Hyla ewingi* and *H. verreauxi* when they are allopatric but dissimilar when they are sympatric.

Isolated groups of sister population undergoing natural selection will loss some of parental characteristics while adopt newer ones. Thus it is expected that either parental genes undergo modifications or new genes are accumulated in the gene pool. In course of time, this event makes the population sufficiently different from the parental group.

3.5.4.5 Chromosomal characters in hybrids

How much genetic differences should there be to consider a species distinct from nearest species. This is an unsolved part. The opinion of de Vries is that a single mutation can give rise to a different species. It is possible if there is allopolyploidy which produces new species in the next generation. Morgan correctly interpreted that several mutations accumulate to give rise to a different species. Morgan termed the various intermediate forms in different progeny as *variants*. Morgan, however, did not established however the number of genes required to be mutated for a new species.

Regarding chromosome number, it appears that many related or non-related species have similar numbers. Therefore chromosome number cannot distinguish species differences.

However, the various sources of chromosomal abnormalities (such as deficiency, duplication, translocation and inversion) were studied for chromosomal polymorphism as well as chromosomal differences among species. The latter technique helped to discover that some minimum number of breakage of chromosome of *Drosophila pseudoobscura* can give rise to *Drosophila Miranda* and this was nearly 100 in number.

Differences in gene arrangement might be regarded as a cue to the evolution of several species of *Drosophila*. It has been observed that 25 inversions of blocks of genes is a difference between *Drosophila flavomontana* and *Drosophila virilis*. But studies on 96 species of *Drosophila* by Carson and his collaborators proved that pairs or groups of related species were homosequential. Therefore gene differences alone cannot be accounted for species differences.

3.5.4.6 Allozyme studies in different species

From 1966, allozyme studies geared up in quest for cues to species differences. Enzymes of different populations studied by gel electrophoresis reveal differences, which is due to different gene expressions. The object of this study is the estimation of genetic differences and similarities between species. However the estimates, i.e. the genetic differences and similarities are not constant for all species. The reasons are many; the process of species formation is gradual, some require more time to accumulate more gene differences. Others evolved from some races. Thus the pathways to species formation are different for different species.

The problem of this study is that alleles code for different allozmes with similar mobility and are said to be identical and the amount of these identical genes is about 80% in different subspecies or semispecies. This in *Drosophila* is about 56% in sibling species, 35% in morphologically distinguishable species under same subgenus.

The studies also indicated that average genetic distance is same between subspecies and semispecies. Still semispecies of *Drosophila willistoni* group acquired some amount of reproductive isolation and they exist as sympatric population.

The genetic distance between man and chimpanzee (King and Wilson 1975) is 0.62 and genetic identity is 0.54. These values match for sibling species of *Drosophila*. But sibling species, by definition, are indistinguishable externally. Thus comparing values and phenotypes of *Drosophila* and those for man and chimpanzee, we can conclude that in latter case, the divergence of regulatory genes far exceeds the divergence of structural genes coding for allozymes. The electrophoresis hardly can detect the divergence of regulatory genes.

Unit 4 ❑ Procedure keys in Taxonomy

Structure

4.0 Introduction

4.1 Taxonomic procedures

4.2 Taxonomic keys

4.3 Systematic publications

4.4 Process of typification and different zoological types

4.5 International code of zoological nomenclature

4.0 Introduction

This part of the **Taxonomy** syllabus consists of the following topics :

4.1 Taxonomic procedures-taxonomic collections, preservation, curating and process of identification.

4.2 Taxnomic keys-different kinds of taxnomic keys, their merits and demerits.

4.3 Systematic Publications-different kinds of Publications.

4.4 Process of typifications and different zoological types.

4.5 International Code of Zoological Nomenclature (ICZN)—its operative principles, interpretation and application of important rules, zoological nomenclature; formation of scientific names of various taxa.

The topics with their respective break up in fact cover up the essential aspects of the working practices of the science of animal taxonomy and systematics. An introductory review of all those items may be presented as follows :

(1) The first item of taxonomic procedures of collection, preservation and curating processes of identification are three basic items in a taxonomic study. **Collections of specimens** or samplings are mainly outdoor exercises in easy to hazardous terrain covering all natural **niches** including high altitude realms to underwater sites in deep oceans having at the same time laboratory facilities for extracting live forms from supporting substrates or by breeding and rearing target samples by appropriate techniques. By studying the intricacies and modalities involved in such complex procedures, we are able to understand that the collection of animal samples for a scientific study needs suitable planning and instrumentation. A collector must be familiar with various gadgets used for his success.

Just as there are various kinds of instrument based for procedures for collection there are gadgets for rapidly sorting out similar forms from a bulk collection as well.

(2) **The process of preservation** following collection in cases where live forms are not required as in most cases of animal taxonomy is also important. Preservation in liquid preservatives or in dry state after adequate processing of target samples needs a careful and appropriate handling. A wide range of techniques is in use for different groups of animals. Parts of specimens are also preserved as imprints of animals, their left out material, their recorded behaviour patterns etc., may also be of critical help in taxonomy. Preservation by curating samples, specimen by specimen, is a hightech subject that needs trained personnel. Photographs and illustrations are most often useful and for critical analysis, computerized data processing and electron microscopy together with biochemical and cytological studies become necessary. Thus, present-day collection for identification of animals is not merely based on any or more samples of the same but includes their behaviour, habits and habitats, their biochemistry and high-blown structure analysis etc., overriding the barrier of light microscopy.

(3) **The process of identification** is the most complex one and needs utmost care and integrity. A gross identification upto ordinal level or to family level can be done by one having either the speciality or the tenacity besides having a generalized theoretical knowledge. But for identification down to species or infra-species, the subject needs to be dealt by an expert after samples as per requirement have been submitted to him. Identification keys to genera and species where available are used, illustrations and key-characters are compared. In difficult cases, attempts are made to establish correct matching between the sample in question and the type form of the species to which it is theorised to belong. Free exchange of relevant specimens are made from one to another centre of study. Adequate processing and packaging are done for safe transactions. Housing and storage for indefinite period of taxonomic collections specially of type forms and reference samples are essential and are done conforming to universal standard by trained and experienced personnel in establishments made specially for such purpose in different countries.

(4) **Taxonomic keys** are ready-reckoning devices mostly on the principle of dichotomous descriptive contrasts of salient features and those are devised for segregating different species of a genus, different genera of a family and so on. Various kinds are in use and for use by amateurs of natural history studies, there are branching type keys or pictorial keys which are easy to use.

(5) **In the item, Systematics (or Taxonomic) publications,** the specialities of the papers, monographs, books and all relevant literature which bring to light through passage of time all kinds of information and appraisal at gross/critical level about the diversity

of the animal life (and other life for us) are discussed as the core matter includes description of characteristics of life forms at different taxon level with illustrations.

(6) **The process of typification** is an important aspect of taxonomic work in establishing any new taxon or filling up the gap in this respect of any known taxon. Here the models for the taxon is fixed either at the time of describing the taxon or while filling up this gap for a described taxon. These models need to be preserved as long possible and are taken and consulted as reference specimens/items for the taxa concerned. These models are called as types of which there are several important ones such as holotype, allotype, paratype, neotype, lectotype etc.

(7) **The last item of the present section, The ICZN–The International Code of Zoological Nomenclature,** is perhaps the most important one as it forms the internationally accepted theoretical basis on which the science of taxonomy of animals rests and is worked out. Framing scientific names for various taxa and classifying them in the most correct manner along with all necessary requirements to important items of the present section (4.1-4.3) are more or less governed by the rules and regulations put in the ICZN from time to time. Anyone practising/working in animal systematics must be conversant with the ICZN, and must abide by the rules and their implications of the same.

Thus through our perusal of the present section we become aware of the following :

- ways and means of collection of animals, their preservation and curating and processing for correct identification and taxonomic study of collected animals.
- consulting/preparing taxonomic keys of different kinds for identification of animals at different taxon level.
- speciality and differences of literature/publications on systematics and taxonomic work on animals compared to those on other aspects of animal science.
- obligatory rules and means of the process of typification of animals to determine and consult various types.
- rules and regulations of the ICZN (International Code of Zoological Nomenclature) which govern the activities of taxonomy and systematics of animals both in theory and practice.

We may now describe and discuss the different section of our present study in subsequent pages.

4.1 Taxonomic Procedures-Taxonomic collection, preservation curating,process of identification

(A) Taxonomic collection : Collections of animals of different groups form an essential part of surveillance and sampling, necessary to assess and understand activity of the animals concerned whether beneficial, harmful or innocuous. Briefly speaking, this helps us to detect species, known or new, and comprehend population density, dispersion and dynamics having bearings on pest and parasite management (PPM), plant protection and Quarantine programmes (PPQ), conservation programmes and many other biological information. Surveys for all these purposes and importance are classified as qualitative and quantitative, the first one helping us to know the relative diversity while the second one is to know the numerical abundance of an animal population in time and space.

Usually, collection's of target samples are made by worker himself or at his initiation by employing standard techniques or method/s he may formulate suiting local conditions in nature that formed his study area. Broad-based efforts are better and collected samples that are outside his target may be profitably dealt with by other workers/organisations as exchange materials. Study-material may be procured direct or by raising them in laboratory: Repositories like national-museums or research centres have variable stocks of collected materials some of them from remote or "lost" areas and often lying unattended. Procuring such collected samples may also be a suitable way to amass and enrich collections for taxnomic studies.

(a) Value of collections : Good collections implying abundance and zero damage (intact samples) are always laudable. These help us to be comprehensive in our knowledge on evolutionary diversitv and distributional overlaps and extent. A comprehensive study on faunistics, speciation and other useful aspect can be attempted if the study can be based on good collections which act as reference tools both during and after the study. Imperfect and insufficient number of samples cannot as a rule be the adequate basis.

Biological classifications now consist of ordering population. In view of great variability of most natural population rich stocks of collected samples are necessary. Museum collection are thus invaluable both in providing unstudied stocks as well as labelled types and materials for reference consultation. With increased urbanization, emphasis is now placed on exhaustive collections in such areas so that extant formal diversity of these areas cannot be missed even if species cease to exist with intensified urban activities with time.

(b) Types of Collections : Different stages of life-cycle of whole samples are collected as a rule. Since taxonomic characters of an animal from all its aspects are considered at present, collections of live specimens are also studied in nature or in laboratory. Modern taxonomists seek to have not only morphoanatomical characters but also such characters which may be (i) ecological characters, (ii) ethological characters, (iii) cytological characters, (iv) biochemical characters, (v) geographical characters etc. For this, collection must be supplemented by material/parts of animals to enable us study as many aspect as necessary. Films of animals' courtship and other behavioural aspects, recordings of their vocalization degrees (as tapes, sound spectrograms etc.,), photographs or casts of animals activities (nests, galls, webs, tracs etc.) should also be collected. Access to a host of infrastructure facilities for biochemical analyses and electron microscopic study, of aquarium, aviary and insectarium etc., is essential for better results for which specialised centres must be consulted as necessary.

(c) Methods of Collections : This varies from such a simple means of catching/ picking/trapping a single specimen by hand without a device or with very simple device from place visited by such one to using elaborate system of equipments and trained personnel for the purpose specially when sampling aims at covering easy to difficult sites.

The method of collection of sample animals either individually or **in mass** form a subject by itself with continuous innovations for the same. Different means are used for different groups which may vary even from species to species level, the keyword of success in all these being the maximum catch at minimum investment. While collection of microscopic forms is based on gathering the substrates that harbour them, the macroscopic forms are collected directly from nature. Caging, netting, trapping and baiting are the standard ways to collect larger forms from fishes to mammals. Smaller forms like various invertab rates are collected by these and other specific techniques suited to their size, habit and habitat. In all cases, enough care is taken to avoid damage to the collected material.

Standard methods usually practised for collecting animals are now briefly discussed as follows-

(1) **Knock down technique :** here, samples are removed from habitat by jarring, by chemicals or by heating, jarring (= shaking) being the most common one for disloging samples from plants. A tray or cloth-piece or other receptacle is placed on the ground below the overhanging target branch of plant which after jarring is gently beaten repeatedly with a stick.

In chemical treatment for dislodgement, substances like methyl isobutyl ketone or turpentine vapour is used. Plant parts treated thus on being shaken are freed from animal, specially the insects in no time which accumulated in the underlying tray/receptacle/cloth-piece or even in a hand net.

For a whole plant, polyethylene envelope with pyrethrum vapour is useful.

2. Plain hand-catching : A resting specimen can be caught off- guard and put into a receptacle with or without a liquid to immobilise or kill it, the whole operation completed by bare hands of the collector. Hand-picking from nesting or resting or feeding sites of samples may also he done. A careful collector may collect impressive number of samples in this no-cost system though in most cases to a limited extent at considerable spending of time. One advantage is that here, the collector needs no preparation and can try it at any point of time at any place.

3. By hand net : One wooden rod (3'–5'long) with a wire-ring fitted to its narrower end (ring diameter 12"–15") and a conical bag of muslin cloth or of fine nylon net or organdy stitched by its broad, open rim to the ring-covering cloth border. There are two kinds of such a hand-net, butterfly net and sweep net (differing in mesh nature of the clothing), both being quite common tools for field collection of insects by amateurs and specialists.

Extracting the insects after trapping them by sweeping across the target surface (s) by the handnets needs deft handling aided by the use of on-the-spot anaesthetizing chemicals.

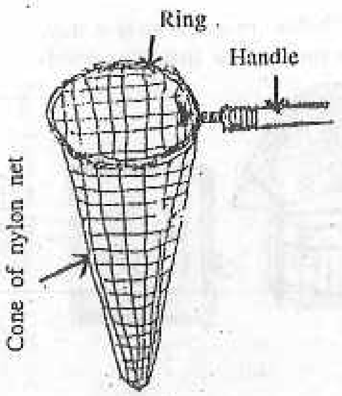
Aquatic insects are collected by **Pond nets**, same as the handnets, except that the mouth of pond nets is semicircular.

More sophisticated net, the **Vacuum net** (trade name D-Vac), consisting of a plastic cone with a removable net attached inside and connected to an engine powered fan by a flexible hose for sucking in target animals, effective for forms not too large as the efficiency of this net varies inversely with the body-size and clining ability of the target forms.

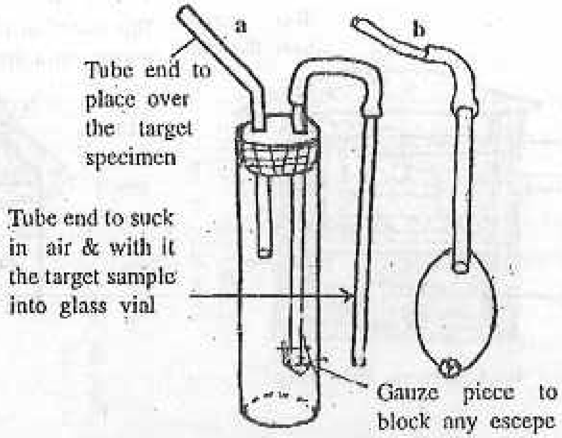
Aerial nets to capture insects on flight are the **Rotary net** (of one or more nets fixed to the ends of beams kept at variable heights from soil level, with nets rotated by a motor-driven shaft).

4. By Aspirator : One simple suction apparatus is used for collecting small insects and arachnids individually while resting or feeding. Suction is generated in bulb aspirator by pumping the bulb vigorously.

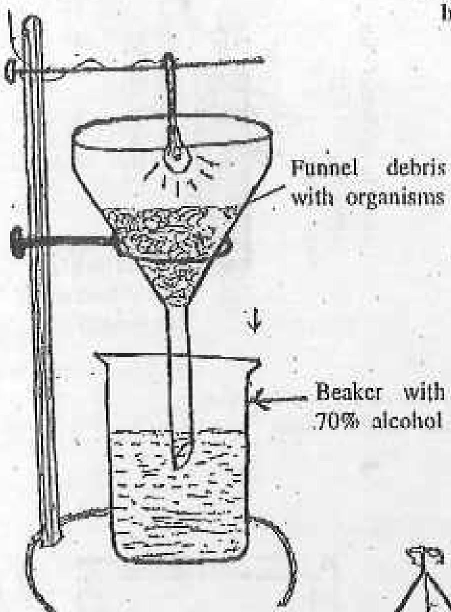
5. By Berlese Funnel : Also called the teslgen funnel, it is quite useful in extracting insects and other small arthropods from organic soils and leaf litter or from loose bark, rotting wood, fungi, mosses, flowers, stored food products, manure etc. The apparatus here consists of a metal or plastic funnel with one wire–mesh inside to hold the sample. The narrow end of the funnel goes inside one underlying beaker having in it some 70% alcohol mixed with a few drops of glycerine. The mouth of the funnel is covered by



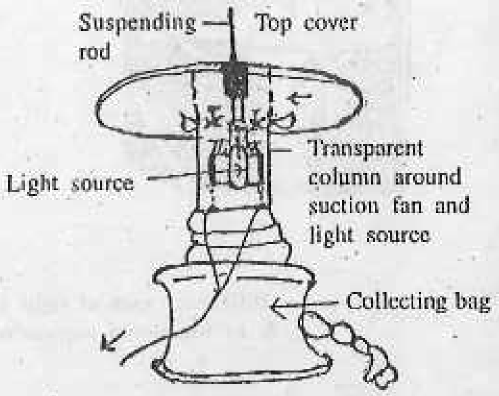
1. Butterfly net



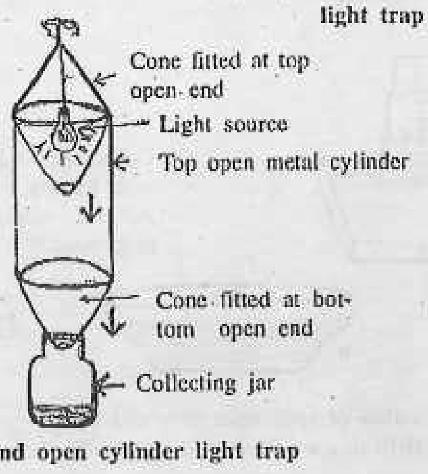
2. Aspirator (a-simple type full view; b-bulb aspirator in part view).



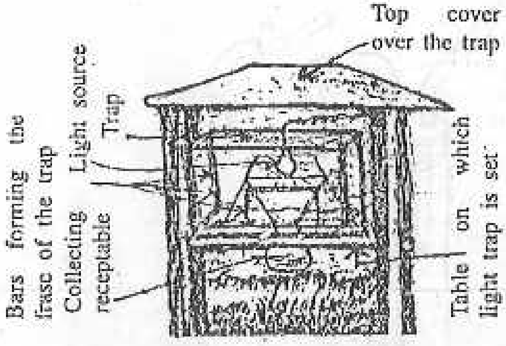
3. Berlese Funnel



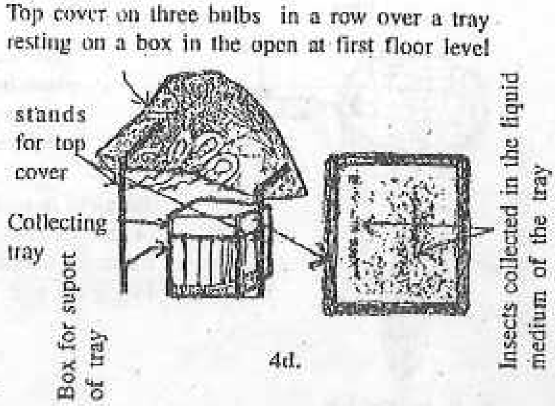
4a. CDC-Miniature suction light trap



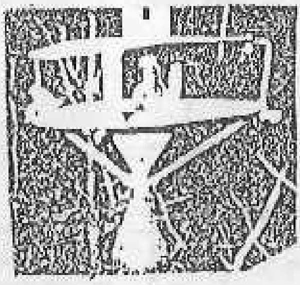
4b. Both end open cylinder light trap



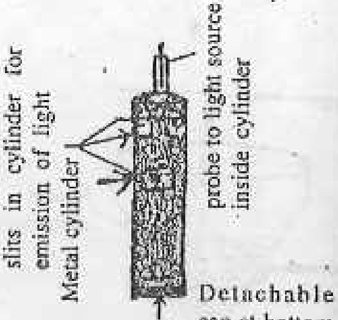
4c. Chinsura light trap



4d.

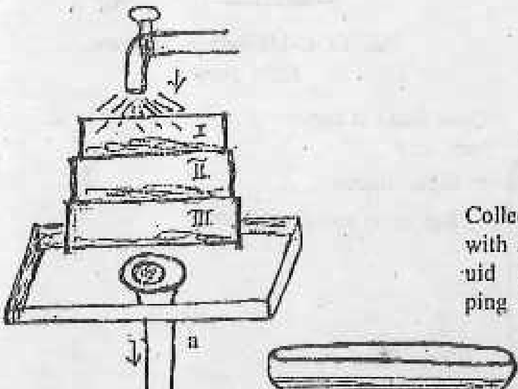


4e.

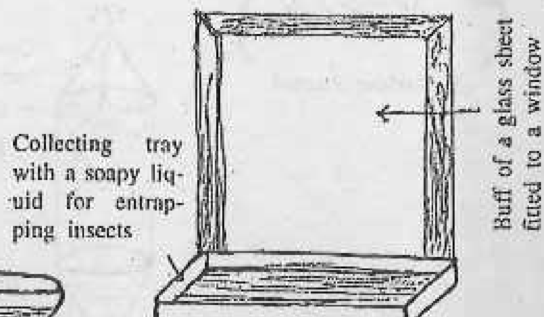


4f.

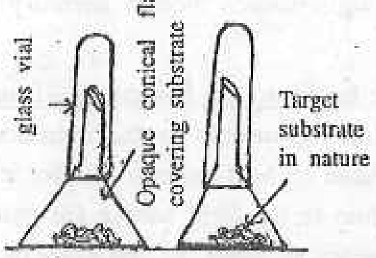
4a-f : Different types of light traps (b, d, e-f local make & in functional suspended state in the open)



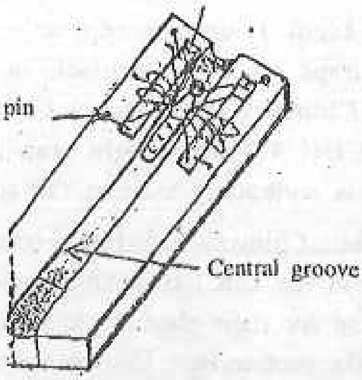
5a-b : set up for extraction of specimens from soil by floating process (I-III in a are the sieves, b = bowl)



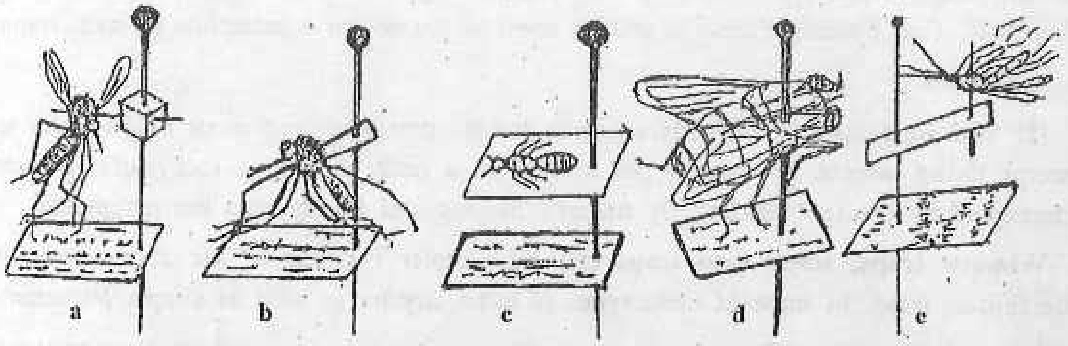
6. window trap



7. Emergence traps



8. Thermocol/soft pasteboard piece with central groove having an insect spread & fixed by paper pieces & pins for fixed-posture-drying.



9. a-e : Dry preservation of insects, pinned/glued variously, for storage and study (taxonomic).

a lid at the middle of which rests one electric bulb of low wattage. As the light is switched on (at a stretch for nights together), the organisms inside sample move away from light (being – vely phototropic and thermotropic) to fall ultimately into the collecting beaker.

6. By flotation method : Used for collecting immature forms and adults of insect and other arthropods from soil or matted vegetation; such substrates collected from open nature is broken up in a basin filled up with magnesium sulphate solution in water (1:3). The content is gently stirred for a while and then left; organisms of the substrate soon float in the liquid surface whence they are collected by a small sieve/filter paper/pipette. This is essentially a mechanical process of differential sieving. Dry sieving, without use of any liquid, is also useful.

7. By Trappings :

a. Light Traps : Insects active at night and positively phototropic are collected by light traps which are available in simple, local forms or as technically modified form as in **Chinsura light trap** or the most effective **Suction light trap (=New Jersey light trap/CDC Miniature light trap** using ultraviolet light source though mercury vapour lamp is commonly used as the source).

While Chinsura light trap a country-made device based on the Rothamstead light trap (used in the U.K.) is a simple collective device drawing insects to the light-source of the trap for their phototropic habit and entrapped due to heat-exhaustion factor of the trap, the suction light trap uses a small fan in addition to the light source for generating a suction force leading to the trap for which no-escape factor of the trap increases. Underwater light traps are used to entrap aquatic insects and other arthropods.

b. Sticky traps : Here, adhesive surfaces of various designs (usually cylindrical) at various height level above ground are used to trap insects on flight from different directions. Tree banding greese is usually used as the adhesive materials in such traps.

c. Others :

(I) Malaise trap : Is basically an open fronted tent made cotton or nylon mesh to incerpt flying insects. Its root slopes upward to a peak heaving a receptacle. Insects intercepted by the tent tend to fly towards the top and finally into the receptacle.

Window traps, water pan traps etc. are simpler versions of the above type of intercepting traps. In some of these types of traps, dry ice is used as simple attractant.

(II) Pitfall traps and Emergence traps : These are simple devices for collecting some kinds of arthropods, the first one a simple receptacular device with a reactive fluid inside placed in a tunnel for letting surface crawlers in advertent entrapped while moving a cross the pit, the second one being simple, conical receptacle with a collecting tube at top and placed on substrate surface in nature that harbours immatures of the target samples and easily entrap the emerging adults in the collecting tube which has transparent surface and hence is the place of choice for emerging adults, phototropic by nature.

(III) Various kinds of nets : Preferably of nylon thread are used for collecting larger forms by mechanical means. **Mist nets** are useful for entrapping birds.

(IV) Bishop fly trap : Made of a screen cone under a vertical cage and baited with carrion or faeces or **Lard can trap** (made of a horizontal cylinder with screen entry cones at each open end with a bait or lure such as dry ice, a live host, or carrion placed on the floor of the cylinder) are useful for entrapping different kinds of flies.

(B) Preservation : Modes to preserve collected materials vary from group to group. Intricacies of these may briefly be stated basing on uses and nature of collected material. There are two levels of preservation.

1. Field level Temporary preservation : Here, materials are enclosed neatly between two layers of cotton wool or cellulose sheets with relevant date written on a card and wrapped in an envelope of old newspaper. Bits of Carbon tetrachloride/Naphthalene/ paradichlorobenzene are added to cellucotton to keep out predators. Many such packets can be stored in a wooden box temporarily for a few years.

Papering consists of enclosing the sample (preferably a soft-trodied insect large wings and/or legs, moth-butterfly-cranefly etc.) in a triangular envelope prepared thus–a paper - piece sized into a rectangle with sides in ratio of 3:5, and then folded such as to form an isoccles triangle.

2. Permanent Preservation : Methods for this are broadly of three kinds:

(a) Preserving sample specimen dry.

(b) Preserving sample specimen in a liquid.

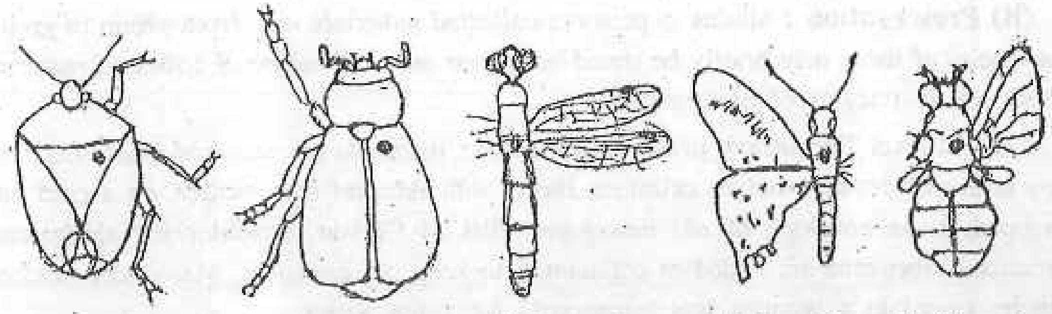
(c) Mounting sample specimen in full or part in microslide for microscopic study.

a. Dry Preservation : By drying and Pinning; insect samples are preserved thus a dead/killed sample (in killing bottle) is 'spread for pinning state' and a rustles entomological pin passes through thorax; such samples kept in drying chamber for a few days after which those are transferred to glass-top storage box with due labelling attached to every pinned sample, some special treatment in these respects being noteworthy:

(i) Direct Pinning : By long, thin and sharp pin (entomological/continental pin) passing through a body – point of the sample with a label of rectangular card beneath the sample. Different body – points are suitable in different insect groups for a pin to pass through and broadly speaking, this is as follows:—

- large bugs (Hemiptera) pinned at mesoscutellum near its anterior margin just right of midline.
- large beetles (Coleoptera) at inner edge of right elytron.
- dragonflies and damselflies (Odonata) at thorax between two hind wings.
- moths and butterflies (Lepidoptera) through middle of thorax.
- dipterous insects specially flies through right of midline in thorax at the level of midlegs.

In all such cases, the pin must pass through dorso-ventral axis of the body.



(a) Bug (b) Beetle (c) Dragonfly (d) Butterfly (e) Housefly

Outline figures of whole insects showing differences in thoracic pinning for their dry-state curation [point of dorsal aspect of thorax through which the pin is inserted is shown by a thick dot-mark (●). Note that pin passes slightly asymmetrically in samples a, b, & e, but exactly through midline of thorax in samples c & d].

(ii) Micro-pinning or Staging or Double Mounting : This technique is quite useful for small insects. An insect in this system is first pinned on a support or stage (Polyporous pith, cork strip or balsa wood strip) using headless, very small steel pin which passes through the free end of the pith/strip and also through the appropriate body – point of the sample, through basal end of that pith/strip.

(iii) Carding and Pointing : Carding is for insects of larger size while **Pointing** i.,e., **triangle carding** is for very small, dry samples. In both cases, the sample is glued to the surface of a strip of Bristol Board Card or the like (best gluing material is clear **cellulose acetate cement**), card strip is rectangular (5 × 8 mm or 5 × 12 mm) for Carding with the sample glued near tip in front while for pointing, it is triangular with the sample glued to pointed tip of the card.

(iv) Relaxing and spreading (or Setting) : Samples after a few days since collection become hard and brittle as they do not survive for long. Pinning of such samples causes fracture in them, so these need to be softened and relaxed which is done by keeping them in a humid atmosphere. Tin can or wide mouthed jar is first filled at its bottom with sand/saw-dust and the same moistened with water and a few drops of phenol or ethyl acetate added to prevent fungal growth. The whole is covered with a piece of blotting paper so that the moisture from bottom cannot directly touch the sample put inside the jar for relaxation. Three/four day exposure softens and relaxes the sample.

Setting/spreading an insect to be preserved dry means to spread body in a straight line with wings and legs stretched horizontally and this is achieved as follows : Place the sample's body antero-posteriorly stretched in the 'medial' groove of a setting/board (locally made from a thermocol sheet or cork sheet) with wings and legs outstretched properly. A long entomological pin is passed through the right point of insertion and slim paper-strips are placed on different positions firmly pressing the outstretched parts of the sample. The strips are kept in place by small pins fixed in inclined manner to those parts. The gut content of the abdomen of the sample thus pinned should be taken out before starting the process to avoid shrinkage of abdomen, specially in case of large, soft-bodied samples. Thus processed and set, sample should be left undisturbed for a few weeks in a full-proof way from predators (by treating storage boxes with naphthalene, Camphor of Paradichloro benzene).

b. Liquid Preservation : Insects and other animals are best preserved in spirit solution (75%-85% ethyl alcohol). Formalin though used as the cheaper liquid preservative for many others, it is not recommended for insects for it hardens them easily. A few drops of glycerine is added in any case, if preservation in liquid is for a long time, to avoid stiffening of samples. Regular checking for liquid preservation to ensure that the liquid has not dried up totally is necessary. Labels written by Indian Ink should be put also inside the tube/jar containing the preserved samples.

c. Preservation by mounting samples in suitable mounting medium on microslides : Small samples are best kept in this manner as those can be put to high power microscopic study without which they can't be studied. Maceration by caustic potash treatment for highly sclerotizel samples is the first step. The samples are then cleared by a dip in clove oil, cedar wood oil or phenol (treated thereafter with xylol in first two cases) and mounted on a microslide in mounting medium like canda balsam solution, or 'Deepex' mountant or Euparol or phenol-balsam mixture (1:1). A cover slip is put over the sample in the mountant and the whole is made bone – dry after keeping for sometime in a constant temperature chamber at 50° Celsius. The dried slides are 'ringed' around their coverslip edges with a varnish to save the sample in the mountant from harmful polluted atmosphere.

(C) **Curating :** After stocks of specimens and their collections are obtained by a custodian Institute or organization of the same for taxonomic preservation and use, the important basic step is to ensure their safe-keeping, cataloguing etc. *i.e.,* curating of the deposited specimens amongst which there are types; additional and voucher specimens or their body-parts (for higher animals), of photographs, films and recordings of or relating to those animals (tape-recordings of or relating to those animals). All are the properties of global science and must be treated on that basis complying with the internationally accepted guidelines as available from time to time in the relevant journal **Curator, Museum Journal** (London), the ASC **Newsletter** (Association of Systematic Collections) etc., besides data on exchange basis. The personnel in a museum engaged in curating must be professional curators having a clear understanding of the functions of collections always attending to the need of updating keeping in mind the groups of animals which needs procurement, areas urgently to be surveyed and various policies about the collections in his Institute. His success depends on his ability to preserve the collections, to gain both in more specimens and infrastructure and maintain readily referrable data about his stock.

A brief review of the essential, activities relating to curating animal specimens in a museum or the like-Institutes/places are as follows :

a. **Housing and Storage:** Collections of animals or their parts or photographs, films and other preparations for study and research should he preserved in a proper manner and stored in air conditioned, fire-proof buildings. Exposure to fluctuating temperature and humidity is harmful. Storage-cases for specimens must be dust-proof and insect-proof. Steel cases built now–a–days as containers are better. National level museums have all such facilities as well as experts and specialised technicians to handle the collections of diverse groups as required. So it is desirable that collections made and studied at other centres be ultimately deposited to such larger depositories which act as reference centres for scholars of the present and the future. Some well-known museums in different parts of the world are – Zoological Survey of India's principal office and select centres and some select branches (India), British Museum of Natural History in London (Great Britain), Bishop Museum in Honolulu (Hawaii), U.S. National Museum and many such centres in other countries.

b. **Arrangement and Preparation of Material :** Essential aspects of arrangement are :

(i) Collections kept in museum in the same sequence as of an animal parade from lowest to highest classificatory taxa.

(ii) Sequence of orders and families should he maintained in arranging material whether identified of not with exception in cases where serially arranged samples are disproportionately unequal in size (*e.g.*, fish group) as very large samples may need to be arranged separately.

(iii) Contents of trays and cases in any arranged gallery must clearly be indicated outside.

Essential steps for preparation of material are : (i) Bird and mammalian skins are studied as sent from the field by the collector, skulls need to be cleaned.

(ii) Liquid/dry preserved material may be studied as those exist. In many cases, study of parts under microscope is necessary (e.g., insect genitalia) and permanent microslide mount of such parts must be made without delay.

(iii) For Protozoans, special techniques are needed for preservation as study -worthy material.

c. Cataloguing : Cataloguing of specimens or other samples preserved in a museum in a most easily referrable procedure must be kept updated as a compulsory house-keeping step.

The old practice of giving every specimen preserved a separate catalogue number specially for vertebrates where specimens are limited in number is replaced by the system of putting areawise collection of all kinds in one catalogue facilitating easy data retrieval and faunistic analysis.

For insect collections, where addition to the museum every year is sometimes of about a hundred thousand specimens, it is the practice to catalogue their accessions by lots with each lot consisting of a set of specimens from a given locality or region. Minimum data entered in cataloguing are : consecutive museum number (lot number), original field number, scientific name (at least generic name), sex, exact locality, date of collection and collector's name, remarks etc.

Type specimens in many, museums are catalogued together usually in a bound book serially from lower to higher taxa. In such cases, curators often have rather elaborate card-filling systems. With time, as collections in museums increased in size and quantity, the elaborate card-filling systems have been replaced by Electronic data Processing (EDP) comprised of several ways of employing computers in cataloguing.

d. Other aspects : Three things are noteworthy in these cases :

(i) Material Exchange : When definitely ascertained that a museum has enough of a species or subspecies samples, it is advisable to donate a part of the same to other repositories trying to procure similar excess stuff, in exchange, but of such taxa which are necessary.

(ii) Discarding useless material : improperly preserved or definitively labelled specimens are valueless. Curator must ensure such items in his stocks and get rid of them for better use of his infra-structure.

(iii) Loans : Researchers are in need of comparing labelled samples of a museum with their material of the same group under study and are often granted loans of museum specimens. Sometimes, specialists are sent unstudied material of a museum for their study, identification and status determination of those material on loan basis.

In every case of such loaning, terms and conditions should be made clear to both the parties and those should be honoured affecting the safety of the materials. It must be noted that the borrowing of museum samples by outside researcher or specialist is a need of the science of taxonomy, so there should not be any stringency except that necessary for the safety of the samples in point.

(D) Process of identification : Identification means to determine the kind of organism or given sample/specimen is and the process involves a group of special activities for correct appraisal. An identification scheme permits placement of an undertermined specimen in one of the taxa which together form a classification. One uses a few characters for identification (ideally a single diagnostic character) lining up the specimen along this or that track of identification. The process of identification is based on deductive reasoning.

Following are the main aspects in any identification process of stray/mass collection of animal samples/specimens :

(a) Sorting of collections : materials collected in study-trips and expeditions are first sorted and tentatively recognised by the broad groups (order and family level) they belong to. This is a sort of broad-level categorisation and is necessary for proper preservation on a long term basis with the prime compliance of cataloguing.

(b) Methods of identification : Museum personnel including the curator may take up their respective group of animals collected according to the specialization. The important methods used in identification process are :

(i) by comparing relevant data on descriptions and illustrations available in literature available as stray papers to monographic work on extensive revisionary basis.

(ii) by running through the identification keys available from literature or as handouts of the specialist of the subject.

(iii) by direct comparisons of material now under study with identified parallels of the same group loaned from outside and

(iv) by combining all the above-said methods for better result.

Concluding Remarks

The topics discussed and reviewed in this section are the practical work aspects of the science of taxonomy in the sense that the material for taxonomic studies composed of samples of animals in their different aspects of morpho-anatomy, behaviour, habit and habitat types, their biochemical structures and processes, their cytological and embryological make-up, this immature stages and life-cycles need to be preserved, processed and conserved as reference material for parallel futuristic studies in such authorised public centres which are meant exclusively for the same having both the physical and manpower compliments as required. What was originally a line-up arrangement and maintenance of dried samples of animals in series of wooden containers together with such additional samples in containers in liquid preservatives or processed and mounted permanently in microslides when very small in size or in isolated container or fitted in open space of the room, if of large size, became with time a more intricate and complex job as newer dimensions are being added to these aspects of taxonomy. Two relevant features are emphasized and briefly now as examples :

(a) Living culture collections : Collections of living cultures of microorganisms such as protozoan animals and animals of such other kinds in which morphology provides little clue to identify. Continuous maintenance of such cultures is highly expensive and needs specially skilled personnel for the purpose.

Cultures, however, are not regarded as type specimens.

(b) Collection of voucher specimens etc. : These are scores of 'additional' specimens which are consulted as supportive or furnishing as the base of research in other aspects of the tax on concerned. They seem to be 'left overs' of study but their conservation and availability for further study remain undeniable and hence well-funded repositories of animal collections try to obtain and maintain them with almost equal care.

The above two and the need to accommodate infrastructure for materials of Molecular Taxonomy besides replacing old methods by newer instrumentations and appliances including switch over to electronic data processing systems make the subject increasingly dependent on more skilled personnel and costlier infrastructure.

4.2 Taxonomic keys-different kinds of taxonomic keys, their merits and demerits.

Taxonomic keys are interlinked, condensed versions of select characters/features distinctive of included taxonomic units arranged such in continuation from start to end-point of a key with scientific names of those taxa at appropriate level of the key so that by using a key to a group of taxonomic units, those units may be neatly identified in a reasonably correct manner by locating the listed features as those exist in concerned units of neutral samples.

Taxonomic keys thus represent an important aspect of taxonomic activity and of taxonomic/systematic publications, Their references as synoptic tables which contain summarised version of many features are inappropriate.

Determination of zoological status (position) of any animal at all hierarchical levels of Zootaxonomy (from Phylum down to infra species level) is a basic exercise preliminary to any methodical interest or investigation centring the animal. This means identifyirg or establishing the identity of the animal as per scientific, norms which may be done by any or due combination of such **three** methods as (i) comparison of the animal/s (*i.e.* identifiable sample/s) with already identified specimens (done by experts) and preserved in Natural History Museums or other recognised repositories (at Zoological Survey of India, in India: U.S. National Museum, in the U.S.A.: British Museum of Natural History, London the U.K. etc.) – Direct Comparison Method, (ii) comparison by consulting published keys to identification and taxonomic descriptions including other available data relevant to the concerned animals, and (iii) taking help of the concerned experts for correct identification of the three above said methods, immediate and **approximately** correct identification may be made by the second method, specially by careful use of a good taxonomic key aided by supportive illustrations. By comparing a sample, feature by feature, with the key-couplets, all the non-agreeing ones can be eliminated and the only one with which it agrees can be arrived.

(I) Purpose, Properties and features : More important aspects here are –

(1) A taxonomic key is essentially a printed information retrieval system into which one puts information regarding a specimen to whatever level the key is designed to reach. It is a systematic frame-work for zoological classification with a sequence of classes at each level. Its construction is based on a thorough analysis of the stable and best possible taxonomic characters.

(2) The purpose of a key is to facilitate easy identification, almost as ready-reckoner for diagnosing identity by presenting contrastable characteristics in a series of alternative choices. A well constructed key also focusses on the natural relationships of the taxon units it covers.

(3) A taxonomic key must use minimum essential characters worded telegraphically but in nature easily comprehensible. Simple, line drawing illustrations for lucid presentation of critical features may add to the value of the keys.

(4) A good key for identification of animals is strictly dichotomous in nature, not having more than two alternatives at any point of differentiation in the key. Ideally, such alternatives are precise and sufficiently definite to identify a sample without a reference to other species. Each of these alternatives is called a segment or a 'lead' or a 'leg' and two 'segments' form a couplet. A dichotomous key is thus composed of couplets of contrasted characters *i.e.,* a two-way choice key and from start to end point, each of the two segments of a couplet leads to the next couplet in the key, either to just next or to subsequent couplet/s (all couplets in the key numbered from start). A segment in a couplet ends either in the name of the identified taxon or in the number of the couplet to which it may lead.

(5) If a segment of a couplet contains more than one characters, the same are stated in order of their relative importance. The most important character is stated first and

this forms the **primary character**, subsequent ones are the **secondary, tertiary characters** etc. Presence of additional contrasting characters in the couplets in a key makes it useful also for samples which may have part/s damaged with one or two characters missing. With only one character in a segment, the key is **monothtic** while with more than one character per segment, the key is a **polythetic key**.

(6) A monothetic, dichotomous key may be written for example as follows (*Dacus* is a genus of fruit fly insects, the key below included its species in India – example below shown in part to economise space) :

1. Wings opaque 2

–. Wings transparent 4

2. Antenna serrate 3

–. Antenna filiform .... *Dacus minuta*

N.B. First segment of the first couplet ends in a number meaning that this particular character exists not in a single species but in a cluster of more than one species, as is the case with the other segment, Number 2 couplet (leading from first segment of first couplet) is then analysed and it is found that while its second segment leads to one single species, its first segment leads to a cluster of species which is numbered 3 and analysed in full to species in couplet no. 3 (a segment taken up subsequently for analysis thus put under a couplet no. in the key). The key then continues with second segment which ends in number 4 and becomes couplet no. 4 for further analyse. Use of a dash and dot (–.) prefix to second segment, is a style with some while some prefer to leave the concerned space blank, unmarked).

(7) In many old time keys including some in recent times, one may come across 3 or 4 segments forming a couplet in an otherwise dichotomous key. This is specially the case while a principal contrasting character in the taxa mass of the key shows differences in more than two ways. Instead of braking this by using extra couplets, some prefer to lump it into one couplet as follows :

Sensu lato* dichotomous** (key to Indian species of genus ***Culicoides biting midge insects, based on female samples only)

1. Functional spematheca one only 2

–. Functional spermatheca two only 4

–. Functional spermatheca three in number 40

2. – (further analysis not shown here) 3

–. ________________ .... species A

The *sensu stricto* dichotomous arrangement of the above is as follows:-

1. Functional spermatheca one only 2
_. Functional spermatheca more than one in number.4
2. ________________________..........................3
_. ________________________..........................Species A
3. ________________________..........................Species B
_. ________________________..........................Species C
4. Functional spermatheca two only 5
_. Functional spermatheca three in number.................40

(further analysis not shown; Long dash mark stands for the character of the segment, unstated here for convenience)

(8) A type of Tabular key which involves simultaneous appraisal of a small set of characters at each level is also in point. Though not strictly dichotomous this type is useful for 'incomplete' specimens (damaged/mutilated when some characters may be missing). An example is as follows (Part key to species of a genus of Calcutta ants) :

3x	1x	2x
3x	1x	2y
3x	1y	4x
3x	1y	4y
3y		

[Explanation of indices in the table (1x, 1y, 2x, 2y, 3x, 3y, 4x, & 4y are used in lieu of species names) :

1x = specimen with stout, conical mandibles
1y = ... with long, linear & slender mandibles
2x = ... with 2- segmented maxillary palp
2y = ... with 3- segmented maxillary palp
3x = ... with antenna of 10 or lesser no of segments
3y = ... with antenna of 11 or more no of segments
4x = ... with pectinate claws in legs
4y = ... with simple claws in legs]

(9) As opposed to dichotomous type keys, are the **Multiple-Entry Keys** or the **Polyclades** whose recent versions are in the form of punch card Indexing. A card with name and character of a taxon bears a hole at a particular point of the card. Dissimilar taxa have cards with dissimilar features and holes at dissimilar points. While similar cards tie up together, one that is dissimilar can not be tied to it thus showing its difference.

(II) Type of Keys : More important taxonomic keys are—(1) Indented Key, (2) Non-Bracketed Key, (3) Bracketed Key, (4) Spider Key, (5) Grouped-type Key, (6) Combination Key, (7) Pictorial Key, (8) Branching type Key, (9) Circular Key and (10) Box-Type Key. An another view of these keys is as follows :

(I) Indented Key : Couplets are indented from left-hand margin of the page in such a way as to show their relative importance at a glance. Thus, two or more members of primary couplets, are nearmost to left-hand margin, the secondary couplet is indented after leaving 4 or 5 species, the tertiary with equal number of species beyond the secondary and so on.

An Indented key has the advantage that the relationship of the various divisions is apparent to the eye from the key itself. It has the disadvantage as the alternatives are widely separated so that it may be used for short keys, Keys to higher taxa or comparative keys. *e.g.* (by a sketchy key) :

A. Wings mostly hyaline

B. Costa swollen at tip

C. Scutellar bristles 1 pair ..... *D. cucurbitae*

CC. Scutellar bristles 2 pair ..... *D. tau*

BB. Costa not swollen at tip

C. ....

CC. ....

AA. Wings mostly opaque

B. ....

C. ....

CC. ....

BB. ....

C. ....

CC. ....

N.B. Features for B to CC under A or under AA to CC being same hence not repeated for AA to CC), Key to 8 species (last six indicated by a short line and not named to **avoid burden for a learner)**

(2) Non-Bracketed Key : Typically dichotomous in nature with alternative features side by side in a couplet for ready comparison, such a key is more economical in space because it is not indented. Specimens to be identified can run through this key forward easily though a backward run across this type of key is slightly inconvenient. Another disadvan-tage is-relationship of the divisions not apparent. *e.g.,*

1. Wings mostly hayaline 2
_. Wings mostly opaque 5
2. costa swollen at tip 3
_. Costa not swollen or tip 3
3. Scutellar bristbes 1 pair .... *D. cucurbitac*
_. Scutellar bristbes 2 pari .... *D. tau*
4. Thorax with median yellow stripe .... *D. diversus*
_. Thorox without median stripe .... *D. dorsalis*
5. ....
_. ....

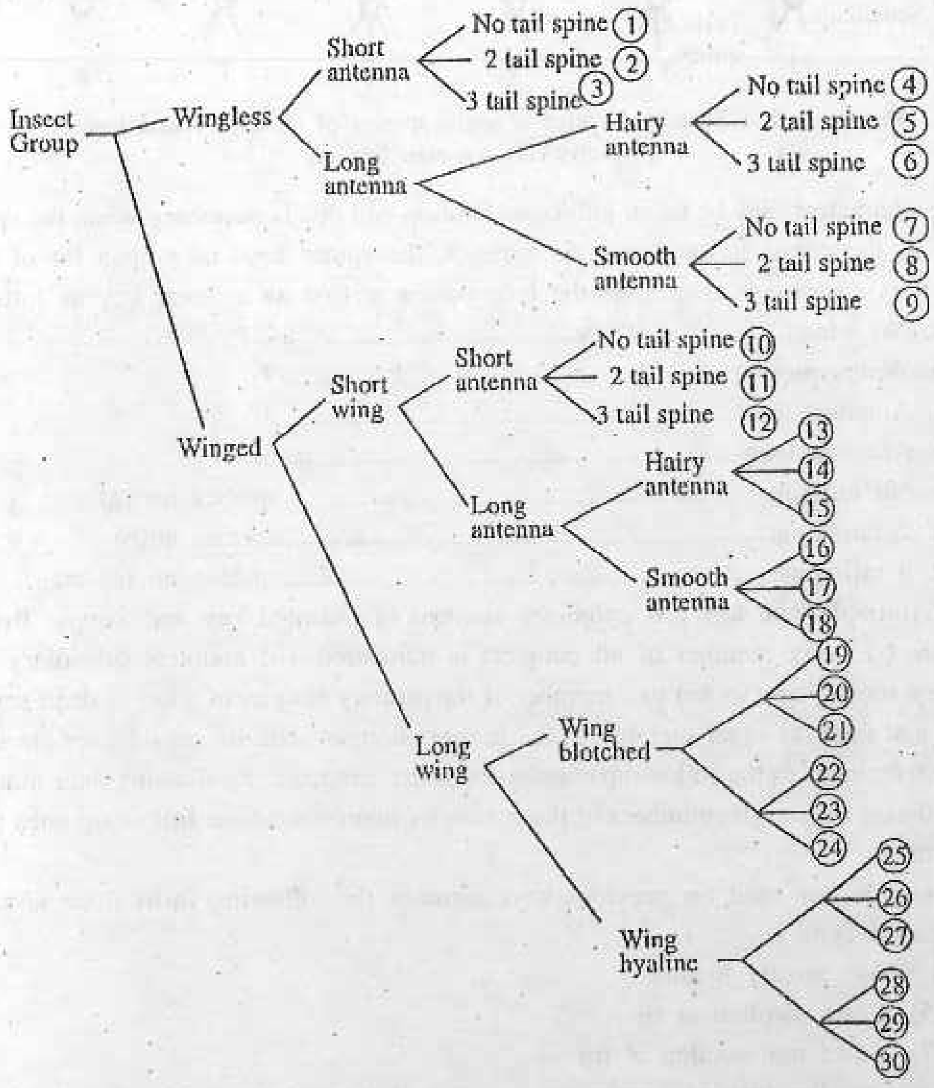
(3) Bracketed Key : Similar to the simple, non bracket key expect that a couplet's continuation is shown here distinctly in the key by inserting the number of the couplet whence the said couplet originates in parentheses just after its own number. One can move both forward and backward through such a key which is said to be the best of all and most used by modern taxonomists, specially when a key is very long covering many units.

Thus, it is to be noted, if a certain couplet no., in parentheses, it is a simple bracket key; if not, it is a non-bracket key. Example of bracket key is as follows :

1. wings mostly hyaline 2
_. Wings mostly opaque 5
2. (1). Costa swollen at tip 3
_. Costa not swollen at tip 4
3. (2). Scutellum bristles 1 pair .... *D. cucurbitae*
_. Scutellum bristles 2 pair .... *D. tau,* etc..........

(4) Spider Key : For gross grouping of species etc., and as a precursor to the preparation of the dichotomous bracket keys, the taxonomists often prepare such basic keys one example of which in brief is stated now—

The, 'Insert group' referred to as in the key represents a hypothetical genus and thirty-end points on right–hand side of the key represents thirty species of that genus, the sorting from genus to species being done on basis of 6 morphological features as—(i) Presence or absence of wings, (ii) Wing short or long (iii) Wing blotched or hyaline, (iv) Antenna short or long, (v) Antenna smooth or hairy, and (vi) Tail spine absent or present (2-3 per individual); a sketchy pictorial presentation of these features is as follows :



N.B. encircled figures in the key stand for species (not named to avoid burden for a learner but marked by numbers, 1 to 8 illustrated in fig 4, as a-h).

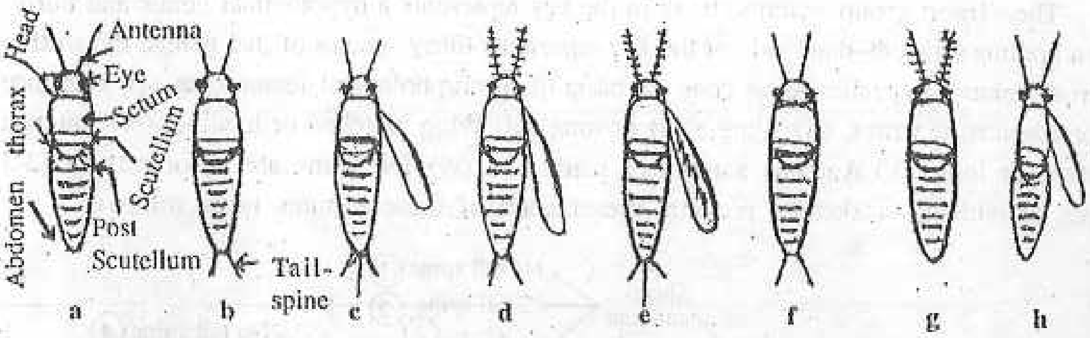


Figure 4a-h : Sketchy pictures of eight species of closely related insects (hypothetical) for classification.

More characters may be taken into consideration and this is necessary when the species number in the genus is too large. As a result, the spider keys take up a lot of room and so it is customary to arrange the information at first as a linear key as follows :

1a. No wings 2
1b. Wings present 7
2a. Antenna short... 3
2b. Antenna long 4
3a. No tail-spine .... species no (a)
3b. 2 tail-spine .... species no(b)
3c. 3 tail-spine .... species no (c) etc.

(5) Grouped-Type key : It combines element of indented key and Simple Bracket key; Here (i) every member of all couplets is numbered, (ii) couplets subsidiary (i.e., secondary, tertiary and so on) to a member of the primary couplet of a key is dealt serially under it and then the other member of the primary couplet with its subsidiaries are dealt, and (iii) references to the follow-up couplet-members are made by showing their numbers in parentheses next to the numbers of those couplet-members whose follow-up ones those happen to be.

The sample key used for previous keys assumes the following form when arranged as a grouped-Type key :

1. (8) Wings mostly hyaline
2. (4,5). Costa swollen at tip
3. (6,7). Costa not swollen at tip
4. —— Scutellar bristles 1 pair .... *D. Cucurbitae*
5. ____ Scutellar bristles 2 pairs .... *D. Tau*

etc.,...

8. (9). Wings mostly opaque

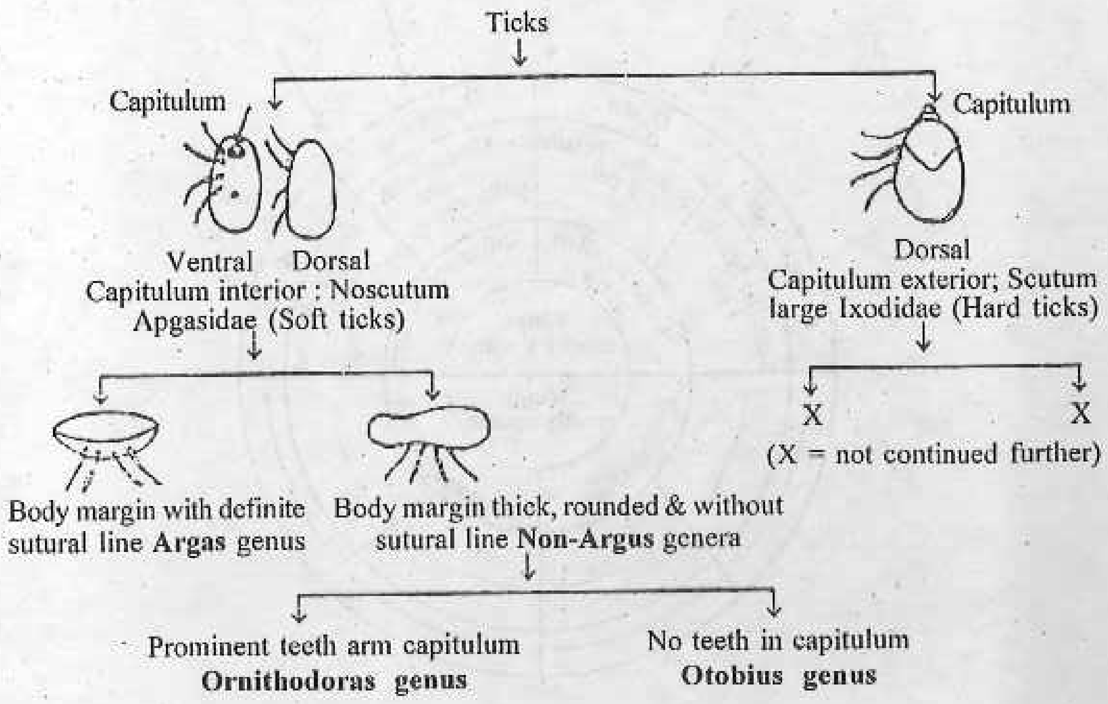
9. (11,12) Wings with stripes
10. (13,14) Wings reticulate
etc., ...

(6) Combination Key : This is prepared basing on good features of Indented Key, Simple Non-Bracket key and Grouped-Type key. *e.g.* :

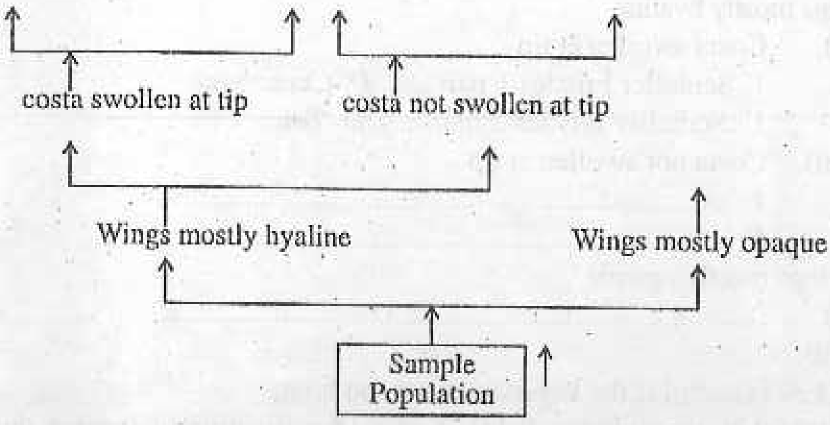
A. Wings mostly byaline
    B. Costa swollen at tip
        1. Scuteller bristles 1 pair ...... *D. Cucurbitae*
        1'. Scuteller bristles 2 pair ...... *D. Tau*
    BB. Costa not swollen at tip
        1. ....
        1'. ....
AA. Wings mostly opaque
    B. ....
    BB. ....

Such a key is useful if the key-size as not too long.

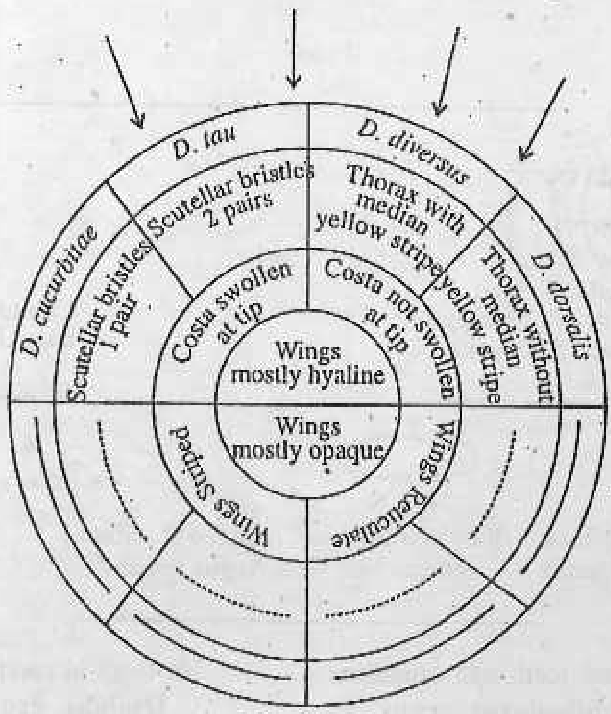
(7) Pictorial Key : This key helps in easy identification of species showing their comparative features (not number) by illustrations in dichotomous plan. It is especially meant for field-workers and non-taxonomists, and medical importance being widely used for pests of agro-veterinary and medical importance. eg. (with ticks)



(8) **Branching Type Key :** Though on dichotomous plan, features are not numbered here. It is an unorthodox type, easy to use for field workers as pictorial key. It is usable with small-size groups—



(9) **Circular Key :** This is also suitable for field workers to cover up works on small-sized samples. *e.g.* (cited below)



(10) Box type key : It has a semblance with the branching-Type key and is quite useful for field workers, *e.g.*,

		D. cucurbitae	*D. tau*				
Thorax with median stripe	Thorax without median stripe	1 pair scutellar bristles	2 pairs scutellar bristles	Scutellum with 5 black spots	Scutellum with 4 black spots	3 hyaline spots in wing's posterior margin	5 hyaline spots in wing's posterior margin
Costa not swollen at tip		Costa swollen at tip		Wings with stripes		Wings reticulate	
Wings mostly hyaline				Wings mostly opaque			
SAMPLE POPULATION							

(III) Computerized key Constructs

(1) Construction of good keys needs shuffling of many character to achieve appropriate combination for separating the taxal unit in a cluster of the same. With accumulation of too many characters and taxal units through newer techniques and letter perecption and instrumentation, manual manipulation for working out clearer taxonomic pictures in respect of sample identification and classification is time-consuming and potentially error-prone. Computerized exercises in these aspects offer a much-sought better method specially for the case with which even an outsized taxonomic construct can be prepared and correction or change of the same later on may be made as required.

(2) Computerization of key-construct at its simplest is composed of **taxon × character data matrix,** its improved version being the **DELTA (Description Language for Taxonomy)** system used in all recent key packages for taxonomic identification.

(3) All key-construct programmes in computerised study programmes are done by scanning all relevant characters at every decision level and determining which one fits best the programmes' prescribed sectional algorithms. In the simplest such a case, the selection parameter (s) is solely ascertained by the equation of the taxan-units that would be forked using that parameter which in turn would reduce key-length ($s=n_1n_2$; n_1,n_2=taxon-units) due to split caused by that parameter.

(4) Recent modification is in the Interactive Computerized Programme (ICP) which involves offering computer's choice of best character at every stage of key-construction with operator's ability to accept or override the same by something different based on his expertise.

(5) Numerous computer-based key-construction packages have been developed with more on the way. For dichotomous key, packages like **KEY, GENKEY** and for polyclades packages like **CABIKEY, CDKEY** are more recent ones.

(IV) Methods in construction of keys

(1) Construction of keys is a painstaking arduous and time-consuming task even for an expert with effective infrastructures as the work involves judicious selection of most useful and most clearly diagnostic characters either from his own study of material or from data available in literature of others' work which he may have means to directly verify or not. In any case, he can be more sure of his collection and selection of character of material covering which he is constructing the key, if he is able to examine the 'types' or the authentic samples of the material in point. He needs to give extra effort and time for those samples.

(2) The constructor of a key must try hard to select such character for his key which will apply similarly to all individuals of a population avoiding age or gender related ones as far as possible. Ideal characters are also **absolute** (two versus one or so; located at top or bottom etc.), **external** (thus directly visible and constant. Sharply contrasts characters with perceptible gradations are also useful but here, one must be careful to use them in the key without the scope of ambiginity (**e.g.** smaller or larger in size, **darker** or lighter) and **overlapping** features (using length 10 to 18 mm versus wing 16 to 22 mm etc.)

(3) In case of taxonomic keys, sorting out right, stable characters with 'meaningful' difference within the populations representing the taxon level to be keyed is the first step. These characters covering different structures and aspects must then by arranged taxon-unit wise (say, species-wise or genuswise etc. and included in the key to be prepared) in a tabular form as follows in part :—

(a) **Example 1 :**

Key to important Indian species (♀ ♀) **Culicoides** genus (Diptera), haematophagous in females only in parr :—

Name of species	Characters from structures and others aspects averaged from species samples			
	Wing surface	Scutal shade	Hind tibial comb	functional spermathecae
1. anophelis	marked by pale and dark areas, apex narroly pale; II radial cell (= r.c.) broadly large	yellowish brown with dark streaks	of 4 spenes; II from spur longest	3; ovoid-subspherical; just unequal in size
2. *brevitarsis*	interconnected pale areas in smoky surface; II r.c. small	pruinose gray with two sublateral dark spots	of 5 spines; I from spur longest	2; ovoid, unequal
3. *innoxius*	circular pale spots in smoky surface; II r.c. narrowly large	dark reddish brown	of 6 spines; II from spur longest	-do-
4. *macfiei*	similar to pale-smoky shading of *palpifer*, apex here narrowly pale; II r.c. broadly large	dark brown	of 4 spines; II from spur longest	3; oval to ovoidal; unequal as in palpifer
5. *oxystoma*	pale spots mostly circular even those at anterior margin & the one at apical angle bilobed characteristi-cally; radial cells absent	bright gray pruinose with brown punctures arrnged in 3 vertical bands	of 4 spines; I from spur longest	2; pyriform, subequal

6. *palpifer*	2 pale spots at anterior margin other pale spots mostly interconnected; apex very broadly pale; II r.c. broadly large	pale yellow	of 4 spines; II from spur longest	3; middle one very large, subrectangular; other two small, ovoid, subequal
7. *peregrinus*	pale spots below upper branch of radius small, circular, that at apical angle bilobed & one preceding it large, conical covering most of small II r.c.	dark brown with two lateral darker bands & two such subcaudal spots	of 6 spines; II from spur longest	2; elongate oval; just unequal
8. *raripalpis*	same as in *palpifer* except that apex not pale; II r.c. broadly large	dark brown	of 4 spines; II from spur longest	3; ovoidal unequal as in *palpifer*

Such tables can include more species and more characters if the relevant key is prepared to cover more species. For preparing a key only to adult males or only to adult females of the species tables as above should than be constructed with characters common in both the sexes others applicable wither to males or to females. Differences in 6 important characters (first five common to both males and females, last one only to females) may be used in more than way to prepare a non-bracket type simple, dichotomous key to the eight species concerned one of which is as follows : —

1. Hind tibial comb of 4 spines 2

   Hind tibial comb of 5 or more spines 6

2. First spine from spur in hind tibial comb longest. Radius unbrached, ... *C. oxystoma*

–. Second spine from spur in hind tibial comb longest. Second radial cell, broadly large 3

3. Scutum dark brown 4

–. scutum shaded otherwise – pale yellow to yellowish brown......... 5

4. Wing apex clearly pale though narrowly .... ***C. macfiei***

–. Wing apex not pale, smoky .... ***C. raripalpis***

5. Scutum shaded pale yellow. Wing apex Very broadly pale .... ***C. palpifer***

–. Scutum shaded yellowish brown with dark streaks. Wing apex narrowly pale..***C. anophelis***

6. Hind tibial comb of 5 spines...........................***C. brevitarsis***

–. Hind tibial comb of 6 spines 7

7. Pale spot at apical angle of wing circular, never touching wing margin. Dark reddish brown scutum .... ***C. innoxious***

–. Pale spot at apicla angle of wing bilobed and broadly touches wing margin, Sentum dark brown with two lateral darker bands and two such subcaudal spots .... ***C. peregrinus***

Since in such keys, emphasis is given on characters which are better contrasted, the selection obviously is some what random in nature. This results after in grouping or clustering of less related species (or taxon-units together and the resultant key though of a much utility value fails to reflect on the photogenic aspects correctly. In the sample key furnished above, species with three functional sparmathecal are evolutionar primitive than those with two. The species *C. oxystoma* is clustered in first segment of complete no. 1 with primitive species like ***anophelis, macfiei, palpifer*** and ***raripalpis*** as ***C. oxystoma*** agrees with these four in having four spines in hind tibial comb in contrast to five or six spines in the same of other advanced species like ***brevitarsis, innoxius*** and ***peregrinus.***

(b) Example 2 : Key to seven common ants (worker caste only, ♀) covering species to subfamily taxon each belongs to in bracket type dichotomous mode for practice-identification work,

Serial/Sample no.	Subfamily status	Genus-species status (Author's name)
1	Formicinae	*Oecophylla smaragdina* Fabricius (Fig.6)
2	Formicinae	*Camponotus compressus* Fabricius (Fig.4)

3	Formicinae	*Camponotus confudi* Forel (Fig.5)
4	Ponerinae	*Diacamma vegans* Smith (Fig.3)
5	Myrmecinae	*Solenopsis geminata* Fabricius (Fig.2)
6	Myrmeciinae	*Solenopsis mtens* Bingham (Fig.1)
7	Pseudomyrmecinae	*Tetraponera rufonigra* Jerd. (Fig.7)

The proposed key to the above-listed species may now be presented as follows ((X) in the key in all cases means the cluster not further pursued because of no necessity now) :-

1. Pedicel of one lobe/node/segment 2

-. Pedicel of two lobes 10

2(1). First gastral segment demarcated from the second gastral sement by a constriction; sting developed, exserted. First gastral segment with all its surface striation marks in concentric arches and with two spines thick at base and directed backwards in its posterior aspect .... **Subfamily Ponerinae** (3)

-. No constriction between first two gastral segments; sting vestigial .... **Subfamily Formicinae** (5)

3(2). Antennal carinae cover antennal bases at least in part. Pedicel free with flexible joints; claws simple; mandibles articulated wide apart at lateral angles. Posterior margin of clypeus defined by a suture. Pronotum with out teeth or spines. Node of pedicel bispinous posteriorly. Claws simple .... Genus *Diacamma* (4)

-. Above-said features structured otherwise .... (X)

4(3). Pronotum with transversely arched surface striae arranged more or less in anteriorly concentric manner. First gastral segment striate and with all its striations in concentric arches. Two spines at posterior end of pedicel thick at base and directed backwards .... *Diacamma vegans*

-. Above-said features structured otherwise .... (X)

5(2). Mandibles long, linear, cylindrical and bent at right angles being dentate at apex but denticulate on inner margin .... (X)

-. Mandibles otherwise, not as above 6

6(5). Antenna 11-segmented; metanotum and node of pedicel bi-spinose or bidentate .... (X)

-. Antenna 12-segmented; metanotum and node of pedicel neither bi-spinose nor bidentate .... 8 .

7(6). Maxillary palp 5-segmented. Mandible long with very broad masticatory margin, the apical tooth acute; curved; thorax, thorax, pedicel and Legs are all elongate but abdomen short, oval; body colour rusty red to yellowish red .... Genus *Oecophylta*: and sample (no. 1) is .... *O. smaragdina*

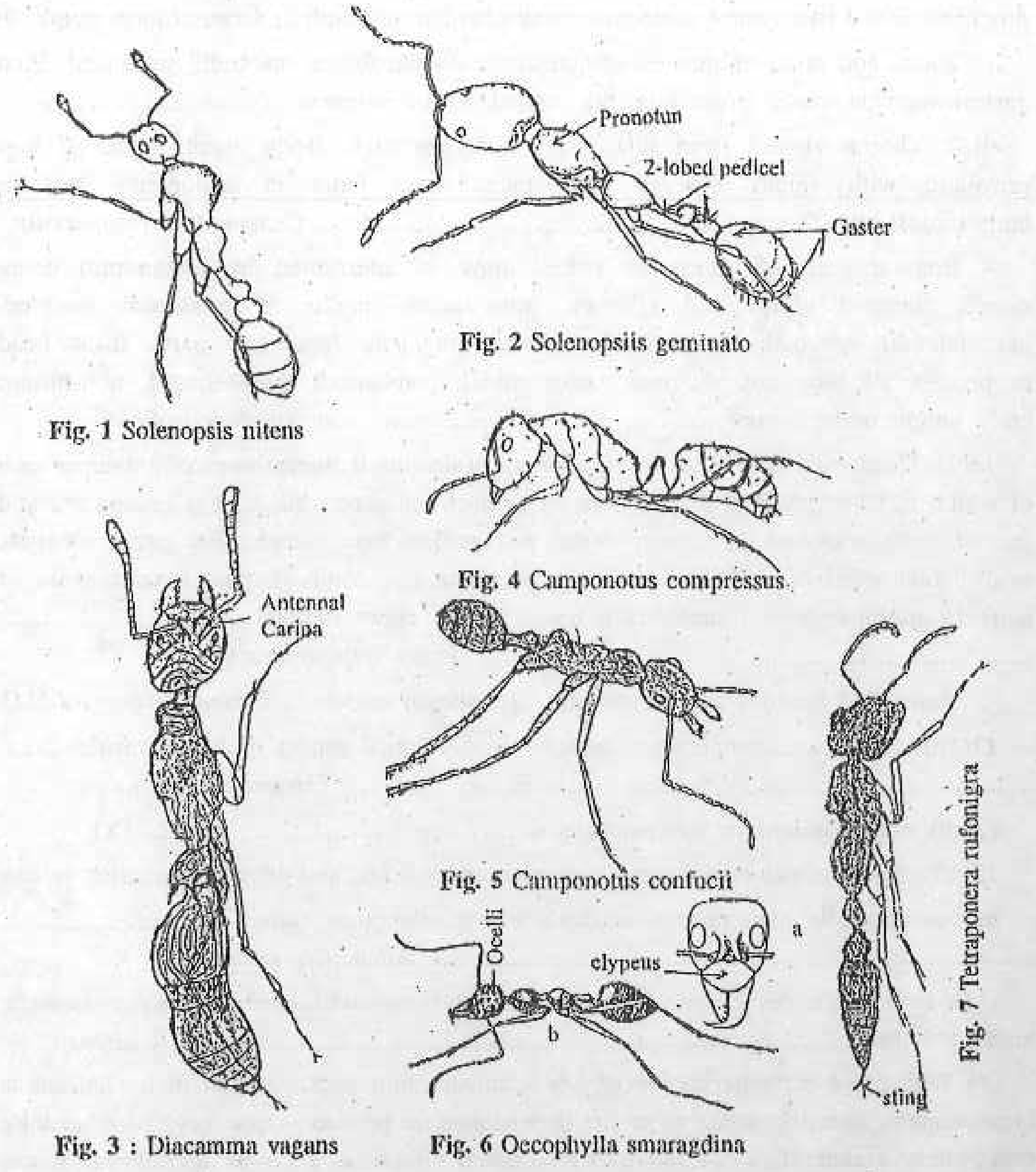


Fig. 1-7 : Outline drawing (free hand) of seven species of ants most common in West Bengal (caste).

-. Maxillary Palp 6-segmented; other features not as above (of the first segment of this couplet ..... (X)

-. Maxillary palp 6-segmented. Other featuers not as above 8

8(6). Thorax and node of pedicel smooth, never dentate/spinous/with angles markedly produced. Basal two gastral segments equal/subequal in length ... Genus *Camponotus* (9)

-. Thorx and node of pedicel spinous/dentate/with angles markedly produced. First gastral segment much larger than the second gastral segment .... (X)

9(8). Thorax viewed from side forms a regular arch. Body black; tibiae of legs prismatic with spines beneath and sparse erect hairs in abdomen's surface; body-length over 9 mm. .... *Camponotus compressus*

-. Regular arch of thorax as stated above is interrupted by metanotum being raised, rounded above and gibbose. Anter-lateral angles of pronotum rounded, not dentate; soft-body grayish black with antennae, legs and parts from head to pedicel all long but abdomen rather small, condensed; quick-footed, non-biting; body length under 9 mm .... *Camponotus confudi*

10(1). Head with visible ocelli; clypeus not projecting between bases of antennae each of which is 12-segmented. Second lobe of pedicel and gaster black, legs orange red and rest of body brick-red iin colour; thorax and pedicel long, slender but gaster elongate oval. Tibial spurs of mid- and hind-legs pectinate *i.e.,* comb-like; no longish mass of hairs (= psammophore) underneath head-capsule; claws toothed .... Genus *Tetraponera* (11)

-. Above-said features are structurally opposite in nature ... Genus *Solenopsis* (12)

11(10). Ocelli *i.e.,* simple eyes present in mid-dorsal aspect of head-capsule .... *Tetraponera rufonigra*

Ocelli totally absent in head-capsule.. (X)

12(10). Body-length over 3 mm.; body smooth, polished and of pale to reddish yellow in colour while abdomen is blackish brown. Antennae rather long .... *Solenopsis gemlnata*

-. Body-length under 2 mm.; body dark reddish brown with head and thorax smoorth, highy polished .... *Solenopsis nitens*

(4) With rapid computerization of key – construction packages and their continuous improvement, question arises as to the dependence on printed – type keys used so long everywhere unilaterally. For laboratory – based situations such as identifying micro organizations, computerized key – packages are more useful than printed key – works as the former permit wider searching in a short time with less effort. But for vast majority of cases of identifying macroorganisms, printed key works are still found more useful

than their packages. Till all round computerized keys using high density storage media like computer disease are available more widely and in user – friendly application modes printed key – works will continue to dominate though it is not difficult to guess that they will be replaced by their computerized form with time totally and universally covering even on the spot identification in field situation. A significant effort in this respect is to computerize all specimens in a museum or a collection or even all museums and all collections through boarding of specimens for electronic storage of their complete data an dissemination of the same for wider use and application via satellite communication system.

(V) Merits and Demerits—Concluding Remarks :

(A) Merits :—

(1) Devising key to species, genus or other taxon level populations is one of the pressing needs to scientifically handle the task of identification in a more or less easier and correct way than by laborious matching devices either with the volume of descriptive data or with the labelled, preserved samples. As new spe ies, genius an infraspecies taxa come to light from time to time, the need for key–ba ed facilit; occupied the centre -stage of taxonomic activity.

(2) For most groups of animals, the most popular and effective means of identification an respect of systematic position has been through the use of taxonomic keys, specially the dichotomous keys, containing the series of essential characters that permit easy separation as one works through them which are in fact point by point verifiable systems having title or no opinion factor and operable even by a nontechnical person with little practice.

(3) Keys form an essential part of taxonomic proc lures as they represent the concise and precise presentation of taxonomic findings.

(4) Good keys consulted by the experts can yield correct diagnosis while a non-expert can organise his non-taxonomic study of his target animals identify them basing on same and can have confirmation later on of his identifications from an expert. Taxonomic keys have thus a very wide application in the act of identifying the animal samples from nature being reliable tools both for the experts and non-experts. For rapid recognition of field samples *in situ*, some types of keys (pictorial keys, circulars, keys, spider keys etc.) are indeed very useful facilitating any emergency decision about pestiferous animals for control programmes etc.

(B) Demerits :—

(1) Taxonomic keys, however concise and precise are highly technical having respective terminologies and stylizations differing widely from group to group. Some efforts and

basic studies are necessary to understand and use the language of the taxonomic keys of a group by a non-expert worker.

Authoritative identification can always be obtained if it is done by the concerned expert of considerable experience and repute. A non-expert with some strains can certainly achieve at least a first - hand identification of his samples working through a relevant taxonomic key even down to species in some cases. For confirmation, he should refer his material and inferences to the expert conversant with the taxonomy of his materials.

(2) Taxonomic keys though an important item in animal identification which again is the prime prerequisite for any scientific investigation with the animals have not been attended upon so substantially specially in respect of invertebrates barring some stray groups of high economic importance as those along with comprehensive studies of related taxonomic aspects deserve. To simplify the point in view, it may be said that to be an expert of the systematics of single family of insects of any area, of a country or of a realism, one need lifetime association and study with adequate infrastructure facility at his disposal. Any deficiency here means, less precise keys whose abundance specially from developing countries add to the complication of key-based analysis. Revisions of past works and attention to move critical aspects are lacking causing further difficulty.

(3) With maximum emphasis on utilarian subjects in recent times, much-needed attention on such basic subjects as taxonomy of animals is neglected it is undesirable that updated and move comprehensive knowledge specially of fauna of developing countries are essential for proper appraisal of the final; biodiversity. Thus the drawbacks of the taxonomic keys of animals, available or not, continue to be treated as unsatisfactory and deficient barring a limited number of thoroughly worked out and updated keys published by the reputed scholars and experts mainly from the developed countries.

(4) Taxonomic, keys which are carefully prepared are indeed of good use so far determination of identity of the taxa involved are concerned.

But such keys are essentially built upon a process of segregation in whatever combination of characters the process brings out the differences of the segregated units most prominently. Thus, these keys are utilarian and not necessarily truly reflective of correct phylogenetic closeness and relationship of the units.

A comparison in the relative efficacy of different types of taxonomic keys merits a reference. All contrived keys are basically dichotomous in nature and each one is indeed effective in identifying the target samples. However, a qualitative difference in them can be made out as follows :

(a) Keys of unlimited character range : Indented keys, bracket and non-bracket type keys, and grouped type and combination type of dichotomous keys, characters from all aspects of target animals are used here which often become too extended. These are effectively usable with basic expertise in the subject.

(b) Keys of limited characters range : Spider keys, pictorial keys, branching type keys, circular keys and box type keys, these involve limited tax on units in a key and very limited type characters are used to prepare them. These are simple, easy to follow a very useful for on the spot identification in field conditions even by laymen.

(C) Concluding remarks :—

(1) Taxonomic keys are devised with core data on salient characters of target groups of animals. Such a key covers different units of a particular taxon level (family level to subspecies level) of a country or of a zone in view, with selected characters interwoven such as to form a running series of couplets, each of two segments of contrasting characters and each segment leading either to one single unit of animals (i.e., a single species etc.,) or to one cluster of such units (shown by a number) which is put into subsequent series of the key till one single unit by a follow-up segment is reached.

(2) To arrive at correct identification basing on taxonomic keys, it must be ensured that the user is conversant with the terms used in the key consulted and also that the key is a 'good' one being prepared in clear format and worded such as leaving no scope for ambiguity. A 'bad' key may cause defective identification but a good; key cannot be held responsible for the same.

(3) In view of remarkable progress in culling characters from different aspects of animal groups aided by complex technical applications, there is hardly any dearth of 'worthy' characters being used in the keys. But it is obvious that lesser the use of characters called through complex technical processes, the use of key is easier. Therefore, the stress on 'gross' features which are easily cullable should not be replaced by complex 'fine' features though none should be minimised. Keys prepared for a group of animals by using morphotaxonomic, cytotaxonomic, biochemical and molecular taxonomic features etc. are not mutually antagonistic but are, in fact, complementary simpler ones should be used as far as possible for routine purposes leaving the complex ones for intricate cases.

(4) Computer application in preparation of keys and identification of target samples are being increasingly attended upon with time. Handling of vast amount of data and their processing for prompt retrieval and searching yielding correct results in shortest possible time show a great potential for a rapid identification work of a sample by using this modern marvel of instruments. There is perhaps no doubt that with more development of computer applications in the field of animal taxonomy, the printed formats which we consult now for identification work may be replaced in full by the computerized discs of key packages. However, the principles of segregation and marking of animals at different

taxon levels, perfected so far since Linnaeus' time, will continue to be the basis of concerned exercises till the science of animal classification rests on existing concepts of speciation.

4.3 Systematic Publication—Different Kinds of Publications

Publication form an essential tool for taxonomy—The science of classification of animals and other organisers, as for other branches of human knowledge. They make possible the wider circulation of knowledge created by individual/collective effort in any place at any point of time which then may be used for any purpose and may provide direction for further efforts in future. People capable of creating knowledge have an obligation "to bring to light their results" through publications.

Taxonomic publications may be of several kinds, ranging from a short description of a new taxon to lengthey monography or handbooks of several volumes covering identification manuals as well as revisionary works and new classifications. Some stress on nomenclatural aspects, other an life history, distribution or illustration. Many different titles are used sing such **key-words** as, **synopsis, review, revision, catalogue, monograph, atlas, fauna, manual, hand book, field guide** etc. major ones may be briefly explained as follows :

(A) Kinds of Publications :

(a) Description of new taxa : There are ordinary description papers of new species, subspecies, gensla etc. Such stray publication are obviously not very comprehensive and do not serve much purpose/unless the taxon units treated in them were of well-known groups or needed an identity due to relevance to economic importance or any biological work.

(b) Synopses and Reviews : Consist of brief summaries of current toxonomic knowledge of a group. Newe taxa are not included in these. Such works actually provide in one cover all scattered information to considerable advantage of a working toxanomist. e.g. a paper titled or "Synopses of Nearitic Ephydridae", published in pp. 151-227 of the journal, **Trans. American Ent. Soc., 1954.**

(c) Taxonomic Revisions : Such works consist of a mix up study of all previous knowledge and those discovered as new during the study undertaken generally covering a perticular germs; somewhat monograph type in nature.

e.g., Revision of the oriented species of *Stilobezzia* kieffer (Diptera : Ceratopagonidae), of 148 pages in the U.S. National Museum Belletin no. 283 published by Smithsomian Just. Press, 1968.

(d) Monographs : These are the most complete systematic publications involving full systematic treatment of all species and subspecies etc., plus a through treatment of comperative structure and biology with data on life-history, immature stages, distribution etc. e.g. paper titled, "Monograph of Cimicidae (Hemiptera : Heteroptera)", of 585 pages, 1966; Thomas Say Foundation publication. No. 7.

(e) Faunal Studies : These are detailed studies of the fauna of a single region, being restricted to a single group of animals, by a specialist of long standing of that group. e.g. Fauna of British India—printed in many volumes covering different groups of animals of Indian subcontinent since 1888, and published by the Zoological Survey of India which continue to update those pesides covering unstudied animal groups in changed titles.

(f) Atlases : These furnish comparative characterd of animals in picture form which are semi-diagrammatic drawings or photographic plates. *e.g.* "Mosquito Atlas", of 44 pages, published by American Entorological Society, 1943.

(g) Catalogues and Check-lists : A Catalogue is essentially an index to published taxa arranged such as to provide a complete series of references for both zoological and nomenclateral purposes.

A catalogue contains the following :-

(i) Original description reference,

(ii) Later references,

(iii) Synonyms with references,

(iv) Range, type-lotality (also its repository),

(v) Type of the genus,

(vi) Miscellaneous pertinent data (like biology, hosts, if any, zoogeography etc.)

Taxa are usually listed alphabetically in a catalogue which is compilation work by an experienced specialist having comprehensive data-base and infrastructure at his disposal. e.g., "Catalogue of the Diptera of the Oriental Region, vol. 1-II.....",—published by the University of Hawai Press, Honolule, U.S.A.

A check-list provides a convenient source of reference for the correct names of specimens and the arrangement of collections. A list of names is a check-list if a careful distinction is made within it between valid names and synonymd and a critically made check-list forms a primary zoological literature."

Check-list are more usefull in better known groups of animals like birds mammals, butterflies etc.

e.g., Check-list of the Lepidoptera of Canada and the United States of America, part I-II, of 177 pages.

(h) Miscellaneous :

(i) Field guides : These are literature made simple for easy use by non-taxonomists to identify the common animals in the field. Some are specially designed in the forms of pamphlets for periodical check of the pests in an area.

(ii) Manuals : Like field-guides, these are also published in simple form including key characters for common species of animals for use of students or layman. Manuals differ as assorted animal forms are included in then [e.g. A manual of the common invertebrats animals (exclusive of insects) by H.S. Pratt 1951 of 854 pp. McGraw Hill Company, N.Y. publication].

(iii) Handbooks : The term 'Handbook' is used for field guides, manuals and the likes (e.g. Handbook of Salmaners of 555 pages, cornell Univ. Pres publication, 1949).

A 'Handbook' is also called sometimes as a 'Treatise'.

(B) Major Features of Taxonomic Publications (Preparation of taxonomic publication) :

Most taxonomic publications contain a set of major components which deserve thorough discussion. It is only in taxonomy that oldest works even remain valuable of consulted universally. Names of descriptions known since Linnaeus (1758) are still of same value components and their formats of taxon publications are as follows :

(a) **Description :** It is the main body of all published works. Its main aim to is to aid in the subsequent recognition of taxon involved. Mainly there are two kinds of description—those of essential characters forming **Diagnosis**, and those of general characters forming **General Description.**

Diagnosis : It consists of brief listing of the most important characters or character combinations peculiar to the given taxon and by which it may be differentiated from other similar or closely related ones (= Differential Diagnosis).

General Desctiption : More or less a complete account of all the characters of the taxon providing also information of interest to othre besides taxonomists. Description published while proposing a new taxon (species, genus etc.) is called the **original description.** It is most important in relation to that taxon as it has two primary functions—(i) to facilitate subsequent recognition and identification and (ii) make available the new name as per ICZN. A good describer must have (i) a through knowledge of the group, (ii) throughness of structure of terminology (iii) ability to assess differences and similarities (iv) ability to emphasize the significant features neglecting irrelevant ones, (v) a full understanding often nomeneclatural technicalities, and (v) concern for future works.

Several important aspects of a **description** are—

(i) Style : For a taxonomic description, language used to describe is always concise and telegraphic. e.g. 'The head is one-third longer then it is wide, the antennae are shorter than the body, and the outer antennal segments are serrate', is written in a taxonomic publication as : 'Head one-third longer than wide; antennae shorter than body; outer segments serrate.'

(ii) Sequence of Characters : Arrangement of characters for diagnosis is different from that for description, characters arranged for diagnosis in sequence of most to least important while for description, characters are arranged from anterior to posterior end of the organism.

e.g., For description of an insect, characters are arranged under such headings in sequence as—head, thorax, abdomen etc.

Comparison of colouration of different parts lend easy but definite identification, but in absence of the practice of describing this aspect in terms of colour names in a standardized literature. This aspects often fails to be of value, use of measuring devices (spectrophotometers) provides good comparison.

Use of numerical data is another important aspect where also accuracy and care involving good number of samples are necessary.

(iii) Illustrations : These are extremely important part of taxonomic descriptions. It is almost mandatory now to furnish illustrations of whole or noted parts of organisms at least in the form of **camera luida** drawings or photographes to complete a texonomic description. Graphs charts etc., should also be added where necessary.

(iv) Keys : To identification of taxonomic units involved, key/s add to the value of a publication and attempt should be made to frame them in the paper having scope for such addition.

(v) Other aspects : Are the bibliography, nomenclatural accuracy and synonyms involved. These pertinent to a paper must be throughly worked out and placed in it.

(C) Format of a Taxonomic Treatment :

Full description of a paper on species which forms of the following items :

(i) Title (ii) Name of the author and with address(es) (iii) Abstract (iv) Introduction (v) Text [Description of species, one or more etc. and such—

Scientific name of species, its Author(s); References of species if any; its type and type locality; synonym and, if any

Description account of one/both sexes as possible with illustration of diagnosing structural parts :

Distribution;

Miscellaneous data, discussion]

(vi) Acknowledgement (vii) References.

An abridged copy of a published paper presented below may explain the highlight features :

"Pacific Insects 12 (4) : 875-882 **30 January 1971**

A NEW GENUS OF SPHAEROMIINI

(Diptera : Ceratopogonidae) FROM THE ORIENTAL REGION[1]

By **Sujit Kumar Das Gupta[2]** and **Willis W. Wirth[3]**

Abstract : Neosphaeromias new genus is described from the Oriental Region, with type-species *gibbus n.* sp. from Laos and Thailand. three additional species are included : *caesius* (Macfie) from Sumatra, *magnus* n. sp. from Vietnam, and *niger* n. sp. from Ceylon.

This paper is the third in a series of revisions of Oriental Ceratopogonidae, with previous studies by Wirth & Delfmado (1964) on *Alluaudomyia* Kieffer, and Das Gupta & Wirth (1968) on *Stilobezzia* Kieffer. The ceratopogonid material which has been sorted and mounted on slides from extensive light trap collections brought to the U. S. National Museum for the study by Wirth & Hubert (in preparation) on the *Culicoides* of Southeast Asia provides a source which we hope will facilitate much needed revisions of other genera of biting midges.

We are especially indebted to the following persons for collection and sending us the material presently reported : M. E. Griffith, D. R. Johnson, and Manop Rattanarithitul, formerly of the U. S. Agency for International Development in Thailand, and J. L. Gressitt, L. W. Quate, and C. Yoshimoto of the B. P. Bishop Museum in Honolulu, Hawaii. Types of our new species are deposited in the U. S. National Museum in Washington, D. C., and the Bishop Museum. Paratypes, when available, will also be deposited in the British

1. Partial results of field supported by grant AI-017223 from the U.S. National Institutes of Health to Bishop Museum.
2. Department of Zoology, Government College, Darjeeling, India.
3. Systematic Entomology Laboratory, Agr. Res. Serv., USDA. Mail address : c/o U.S. National Museum, Washinton, D.C. 20560."

Museum (Natural History) in London; the Zoological Survey in India, Calcutta; School of Public Health, University of Sydney, Australia; and the Applied Scientific and Research Corporation of Thailand in Bangkok.

Neosphaeromias Das Gupta and Wirth, new genus

Type-species : *Neosphaeromias gibbus* Das Gupta and Wirth, new species.

Diagnosis : Species of moderate to large size; body coloration brownish black to black; strong erect spine present on anteromedian margin of scutum; fore femur swollen with 10-30 stout ventral spines; fore tibia arcuate; tarsal claws each with small, external, toothlike process usually present, in ♀ also with a lamellate internal barb.

Head : Eyes bare, their inner margins (fig. 1a) tending to meet in frontal part of frontover-tex. Antenna long and slender, in female (fig. 1b) with segments 3-10 short, oval to barely-cylindrical; 11-15 strongly cylindrical with slightly uneven contour. Maxillary palpus (fig. 1c) in both sexes with last 2 segments pale, the first 3 dark; 3rd segment slender, without sensory

....

"shading. *Abdomen*; Color intensely blackish; terga with scattered small setae and some long marginal bristles. Female with internal sclerotized gland rods absent; 8th segment without hair tufts or sclerotization. Spermatheca (fig. 11) one, strongly sclerotized, suboval to subsphe-rical, with prominent slender neck. Male genitalia (fig. 1n) with 9th sternum narrow; 9th tergum prominent with shallow to deep caudomedian notch and a pair of setose apicolateral lobes; basistyle with well developed mediangular process; diststyle slender with pointed, hooked tip; aedeagus (fig. 10) with slender basal arms, main body broad; parameres separate, long and lamellate, with rounded tips.

Discussion. The sessile media, absence of macrotrichia on the wing, ventral batonnets of ♀ 5th tarsomere, and absence of internal sclerotized gland rods in the ♀ abdomen are characters placing *Neosphaeromias* in the tribe Sphaeromiini. The stout body, ventral black spines of fore femur, 8th abdominal segment of ♀ without tufts or sclerotization, and presence of 2 radial cells are similar to *Sphaeromias* Curtis, but the short costa and presence of a strong external tooth on the ♀ claws are quite different from that genus. The combination of the strong external tooth and the internal lamellate process on the ♀ claws of 2 of the species is unique in the tribe Sphaeromiini. In Wirth's (1962) key to the genera of Sphaeromiini and related tribes, *Neosphaeromias* was keyed out in couplet 16 as "New Genus (S. E. Asia)" near *Mallochohelea* Wirth and *Nilobezzia* Kieffer.

KEY TO THE SPECIES OF NEOSPHAEKOMIAS

1. Small species, ♀ wing less than 2.0 mm long; wing with brownish streak from middle of anal vein small and vague; tarsomeres 1-4 entirely pale, only 5th dark brown

... **gibbus** n. sp. Large species, ♀ wing more than 2.0 mm long; wing with brownish streak from middle of anal vein prominent and almost reaching posterior wing margin; at least 3 distal tarsomeres partly or entirely dark brown 2

2. Dorsal surface of scutum with patches of silvery pruinescence .... **caesius** (Macfie)

Dorsal surface of scutum dull black or with vittae of dull grayish tomentum 3

3. Tarsomeres 1-5 partly or entirely dark brown, none totally pale; 5th tarsomere of female with batonnets covering only proximal half of tarsomere .... **magnus** n. sp.

Tarsomeres 1-2 entirely pale, 3-5 each partly or entirely dark brown; 5th tarsomere of female with batonnets covering entire length of tarsomere .... **niger** n. sp.

Neosphaeromias gibbus Das Gupta and Wirth, new species Fig.1

♀. Small blackish species; wing length 1.75 (1,69-1.79, n = 15)mm; breadth 0.63 (0.61-0.64, n = 15)mm.

Head : Dark brown. Eyes large, broadly separated on their inner margins ; vertex small,"

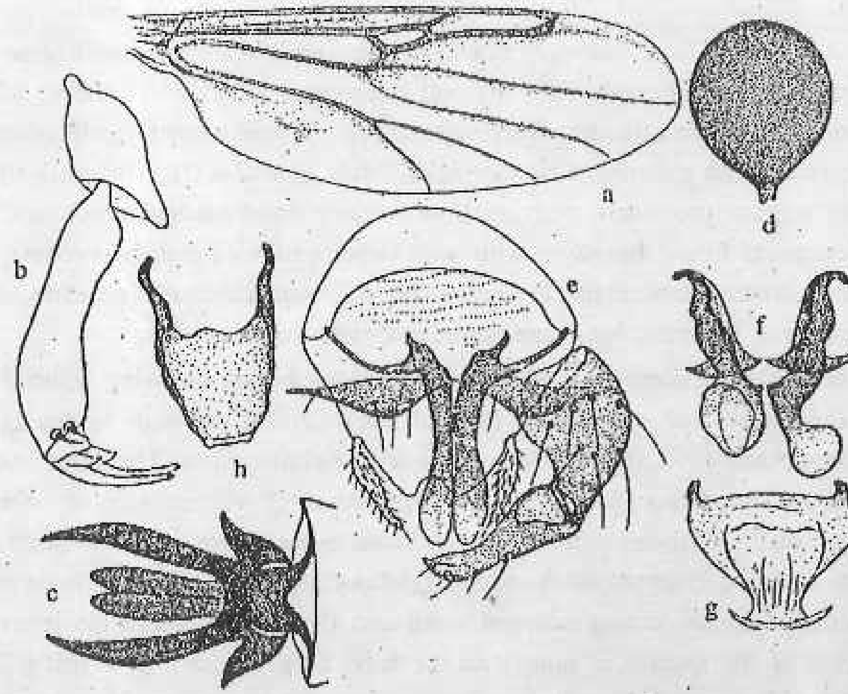


Fig. 1 *Neosphaeromias gibbus,* ♀ (a-h) : Line sketches (*camera lucida aided*) of several stuctural parts : a-wing, b-last two tarsemeres and claws, c-details of pair of clas, d-spermdtheca, and e-h : ♂ genitalia (external).

....

with "feebly spiculate; 9th tergum subtriangular, its caudal end tapering with caudal margin mesally notched, a pair of slender, setose, apicolateral lobes present. Basistyle stout at base, mediangular process large; dististyle stout at base, narrowed abruptly past middle, its tip bluntly hooked. *Aedeagus* (fig. 1o) a broad, lightly sclerotized plate; basal arms slender and slightly crooked; main body broad, the caudal margin blunt with tip sometimes flattened, caplike (fig- 1q). Parameres separate, strongly sclerotized, each with slender anterolateral process and shorter anterior process; main portion long and clavate, with rounded caudal tip; in one slide (fig. 1p) foreshortening produces the appearance of a strongly capitate tip.

DISTRIBUTION. Laos, Thailand.

Holotype ♀, allotype ♂, Loei Prov., Thailand, June 1959, Manop-R., light trap (Type no. 70655, USNM). Paratypes, 3 ♂♂, 52 ♀♀. LAOS : Muong Sing, 7.VI.1960, L. and S. Quate, 1 ♀. THAILAND : Same data as types, 3 ♂♂, 42 ♀♀. Khon Kaen Prov., Ban Pai and Choom Pae Dists., V.1959, Manop-R., 8 ♀♀. Udonthani Prov., Nong Han Dist., VI.1959, Manop-R., 1 ♀.

Discussion. Neosphaeromias gibbus is apparently abundant in Thailand, as evidenced by the relatively large number of specimens taken in light traps. Some differences appear in the ♂ genitalia, according to orientation of the slide mounts, and an extreme is figured in which the parameres (fig. 1p) and aedeagus (fig. 1q) are foreshortened due to nearly perpendicular orientation on the slide."

....

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Concluding Remarks : Taxonomic papers are different in style, content and overall treatment from papers in other branches of human knowledge. Maintenance of correct niceties are essential; so, preparation of a taxonomic paper and proof-reading of a manuscript must be done with extreme care, copies of a published paper should have wide circulation and inclustion in such referral volumes of International Standing as— The **Zoological Record** (published from the U.K.*) and the **Biological Abstracts** (published from the U.S.A).

Thes copies are often called as :

(i) Author's extras : pages removed unchanged from extra copies of the publication and so often contain parts of other papers.

(ii) Separators : These are copies printed from the same type as the original minus the extraneous matter; almost similar to original.

(iii) Reprints : These are copies rearranged to fit most satisfactorily the presentation often paper in a printed from retaining all the traits of the original (through pages may be renumbered and somewhat rearranged and so not the exact copy of the original).

The Zoological Records provide in a series of annual volumes, a bibliography of essential data of taxonomic literature and other basic zoological literature published throughout the world since 1864. It was a British Enterprise (C/o Zoological Society of Landon British Muesume History and Commonwealth Institute of Entomology) but from 1980, collaboration of Biosciences Information Service, U.S.A. is being also utilized now, however, its publication is 4-5 years behind schedule.

The taxonomy part of Biological Abstracts have undergone a change. Since 1970, references on Insects, mites and arachnids of Biological Abstracts are being published separately as **Abstracts of Entomology**.

4.4 Process of Typification and Different Zoological Types

In all works related to binomial nomenclature of zoological systematics, the basic features (= Characters) are taken from specimens (= samples) collected in nature. Various 'type'/forms are selected from them and these 'types' are the standard of reference for them pertain to their taxonomic data. In other words, a 'type' is a zoological object on which the original published description of a name if based. **Typification is the fixation or determination of the type material for a zoological name at different taxon level at the time of first published description of that name by a concerned taxonomist or in absence of types by loss or damage or non-fixation at the time of their first description, their types, by a revising or subsequent expert who selects types from duly preserved samples of the first describer of a zoological name or from his own**

collection of samples preferably from the first describer's locality of collection of concerned samples. The process must conform to the norms and stipulations laid down by the International Commission on Zoological Nomenclature (I.C.Z.N).

(I) Essential Features : (1) A 'Zoological type' is the objective basis with which a certain 'Zoological name' is linked permenently and designated 'type' cannot be changed unless very necessary.

(2) The 'type' of a nominal species is **a natural specimen** (= **Type-specimen** of that species), that of a nomial genus is **a species** (= Tycp-species of that genus), and that of a family is a genus (= **Type-genus** of that family). Depending on their relative importance to the expert determining the types or on the criteria of their determination, types are variously labelled and categorised dispelling any arbitrariness in their relative quality. This process of categorisation is the main task of typificetion which at a taxon level, say species level, say species level, for a species means in fact the act of labelling the specimens of that species used in preparing its taxonomic description for the first time or its any subsequent description after the **appropriate type names.** In short, **typification** is the act of **specimen labelling, species labelling** and **genus labelling** so that the labellings using appropriate names could be the material reference for any subsequent work involving them in respect of concerned samples collected from nature from time to time.

(3) The type concept (= Type Method) to establish a zoological taxon by name actually matured in last 70 years. Previously, taxonomists used to guided by the Aristotlian concept of types. The idea was rather vague and it was held that there were as many types as there were typical specimens of a species whose taxonomic description is based not merely on types but as average of many of that species. Types are not meant to be exclusive basis or even the tertiary basis of the description whose salient features should, however, prevail in the types increasingly from peripheral to the centric one. A species consists or variable populations. No single species can essentially project this variability; type cannot be typical of a species. But a type remains the standard "name bearer" of the taxon it represents.

(4) At the onset of the present form of toxonomy dating from the Linnaeus' time, typification practised somewhat casually. Linnaeus himself never designated any specimen as the type and had the habit of replacing his old 'type' by the better new ones! This continued until the taxonomists started labelling one specimen as the 'type' and the others as 'cotype' (= paratypeof recent taxonomists). With time, many more kinds of types difined from different aspects were in use a study (of 1940) listed ove a hundred of such type names grouped into three categories (seven categories, as per one study in 1967).

Some of the type-and group-names, mentioned above, are out of use now while a good number have found a wide acceptance by the practising taxonomists.

(5) Simpson (1940) coined the term **Hypodigm** as the name of the whole lot of specimens available to a taxomomist at any point of time and recognised by him as members of one taxon i.e., species (= conspecific). This term is widely used by the Palaeontologists though many zootaxonomists are reluctant to accept it as, in their view, the term is essentially a synonym of 'material', a term used by them usually to refer to their animal samples under study.

(II) Important terms for specimen typification : This in other word is the act of determination of category of types out of specimens of a species for its taxonomic reference.

Some 12 catogories of types are commonly used under two broad divisions as follows (explained mainly) in respect of specimen typication in a species.)—

A. Primary Types (= Proterotypes) :

These are fixed at the time of description of the taxon (species etc.) by the author of the taxon out of specimen/s of the taxon at his disposal, The more important Primary Types of specimens are as follows :

1. Holotype : One specimen of any sex selected by the author as the 'model' sample of his species; a true type, this is the most important all types. When a species is described on basis of a single specimen, the same unavoidably is marked by the author as the holotype of his said species.

The holotype is the key to the name of the species and settles questions in connection with the name of the species itself. However, it need not be the type of the species and settles questions in connection with the name of the species itself. However, it need not be the type of the species, nor even necessarily a typical individual of the species; it is the type of the same.

2. Allotype : A specimen of the same species as the holotype but being the sexual opposite of the holotype, i.e., if the holotype of a species is female, a male sample of the species will have to be fixed as the allotype of the species. It can be designated subsequently.

The zoological code does not favour the use of allotype which is viewed as a mere paratype. Its use, however, is of advantage in adding sexual characters ofthe opposite sex of the holotype.

3. Paratype : While describing a species on basis of a good number of specimens, its author selects several specimens for basing his description of the species. He marks one of these as the holotype and a sexual opposite of the holotype as the allotype. He then labels the remaining specimens as paratypes (i.e., specimens of paratype status).

The early practice of labelling 'type-seires' specimens as 'types', 'co-types', 'syntypes' etc., does not facilitate an author to treat his specimens of a species differentially in spite of presence of natural variations in those specimens. All these specimens are given 'equal' importance which obviously is not the correct feature. Typing them as holotype, allotype and paratype, their differential importance is duly pointed out.

(4) Chirotype : This is the type specimen upon which a species name in manuscript is based, i.e., type in pre-published account of a new species (or of a genus etc.).

(5) Metatype : A specimen compared by the author of a new species with the type and determined by him both as conspecific.

B. Secondary Types :

These typicfications are mostly done not by the original author of a species but by a revising author. More important secondary types are as follows—

(6) Homotype (= Homoeotype/Homeotype) : A specimen compared with the type by a person other than the describer and determined by the said person as conspecific with the type. This is generally done when original type is damaged or lost. A homotype is important as a type.

(7) Lectotype : If it is seen that the original author of a species has life his concerned specimens of a species duly preserved and named (i.e., identified but labelled as of scientific value or without any typification at all and the said species thus no individual type labelled anywhere, a revising author/-researcher then selelct one specimen out of those syntypes and typify it as of holotype status for the said species. Such a holotype, recognised by its type-status not during the original description of the species but titled so sub sequently is called the lectotype of the species, with the remaining scientific specimens of the species called the paralectotypes. The deficiency of the holotype individual of the species is thus compensated by the 'creation' of the lectotype individual.

Selection of a lectotype must be done very carefully and by a specialist of the subject concerned having considerable expericne as such a work needs consideration of the following :

(i) If syntypes of the concerned species are preserved at more than one place, it must be checked if all can be accessed upon for consideration. If not, the slection then should be made from amongst the pool of maximum number of available syntypes;

(ii) If any of the preserved syntypes of a species was based upon for description or illustration of both, of the said species, by its original author and the same mentioned or indicated in his original text in point. With other things being equal between such a 'mentioned or indicated' scientific specimen and other scientific speciments (i.e., their quality as a preserved lot is the same the determining choice becomes limited to the "mentioned or indicated" scientific specimen for the obvious fact that only the said specimen was used as a sort of 'holotype' for the species by its original author and though holotype-labelling was not made, the concerned specimen only enjoyed that status to the original describer of the species concerned.

(iii) If syntype specimens, marked out so by the original author of the species concerned, are from different localities but the type-locality for the said species is marked out clearly by the concerned original author or by a reviser of the original work, syntypes only of the said marked-out locality will be considered for fixing up the lectotype.

(8) Neotype : If due to loss, destruction and damage or due to other reasons, specimens of type value and correctly so labelled do not exist or are untraceable and believed tobe permanently out of access, a revising worker of that species may select a specimen (collected by him and identified by him as ofthe said species) labelling it as of holotypic value for the species. Such a type is called the neotype of that species. Neotype stands for the species in absence of its holotypic, lectotypic or syntypic specimens.

Nomenclatural code does not support and furnish any typificational provision for the creation of a neotype for any and every species merely lacking in its regular types (holotype, lectotype etc.).

Neotype creation is recommended only '... when a neotype is necessary in the interest of the stability of momenclature'. In such a case of creation of type of allotypic value and of paratypic value is also recommended for that species if its suitable samples are obtained by the reviser, two such created types being called as **neoallotype** and **neoparatype** respectively.

(9) Plastotype : A plastercast of a type of a species forms the plastotype of that species. If is extensively used in palaeozoology.

(10) Topotype : It is a specimen of a species which is earmarked as 'collected from type-locality' of the species by a reviser or a subsequent worker who may collect and identify the sample himself. It is quite a valuable type specially when original type gets lost or becomes inaccessible.

The type-and topotype-locality of a species are the one and the same and the populations of the said species the said locality are known as the topotype populations.

(III) Important terms for species typification : The typification of species essentially is the task of selecting a species of genus, both being validly described either before or at the time of selection. The species is called the **type-species of the genus it belongs to** and it is taken more or less as the bearer of the typical characters of its genus. The position of a type-species is quite important and previously it used to be called as the **genotype species.** To avoid any confusion involving this term Genotype species with its counterpart term used in the science of genetics (where **Genotype** means hereditary) and genetic constitution of an individual), the use of the term genotype in taxonomy is forbidden by a zoological code of 1961.

The selection of type-species of a genus, *i.e.*, species typification, for a genus, may be any of the two following kinds :

(i) *Type-species, by original designation, i.e.*, a type-species determined at the time of establishment of the genus it belongs to,

(ii) *Type-species, by monotypy, i.e.*, a type-species of such a genus which was established with only that species under it, there being no other species known in that genus at that time though subsequently, more than one species belonging to that genus may be described.

A third kind, *i.e.*, **Type-species, by tautonymy** may be made. Here, the type-species selected is such that its generic name and specific name are *one and the same, egs., Bison bison, Gorilla gorilla* etc.

In some cases, even the subspeices part of the name may be also the same as the species and the genus part of the complete name of the subspecies of a species (*e.g., Apus apus apus* the three parts respectively being the genus, species and the subspecies name.

(IV) Special kind of typification : In some cases, specially in Prokaryotes, bacterial forms etc., biochemical features are essential for identification and for this, those forms need to be maintained in laboratory in live states for idefinite period. Thus their cultures are to be maintained. Whenever particularly such a culture is referred to, it is called as the **Type Culture,** as it forms the basis of species description. If such a culture is lost or destroyed for unavoidable reasons, a new one is started and maintained as its substitute and this substitute new one is called as **Neoculture** or **Neotype culture.**

In case of Protozoa, samples which form the basis of description of a species are all preserved mounting them permanently on a microslide in appropriate-mounting medium after due processing including staining of the specimens as required. A single specimen of such a slide has no special value. Any of these specimens thus preserved in a slide is called as **Hapnotype** a special type in the realm of typification, and the microslide containing them is called as the **type-slide** of the concerned species.

(V) Data on types, type labels and type deposition : All collected specimens should be properly sorted, processed, identified and labelled as necessary. Essential data should be indeliably written or printed in a durable piece of label for every type specimen to which the label must remain tagged permanently. Those data for a label are :

(i) taxonomic identity of the type (its scientific name with author's name and family it belongs to,

(ii) sex of the type,

(iii) locality name of its colletion,

(iv) date of collection,

(v) mode of collection,

(vi) Name of collector(s),

(vii) Other data (behavioural peculiarity, breeding habit, habitats etc., as observed during collection).

For a quick recognition of the various 'types' in the study material of specimens of a taxonomist describing his new species, it is the couvention to use labels coloured differingly for the holotypes, the allotypes and the paratypes and as follows :

Red or **Pink** coloured label for holotype;

Green coloured label for allotype;

Yellow coloured label for paratype.

The secondary equivalents of these three primary types are neotype, neoallotype and neoparatype and these three secondary types, the labels coloured as for respective primary counterpart may be used. Otherwise, white coloured labels should be used for these three secondary types.

Custody of types, their deposition : All types are properties of science and are irreplaceable and indespensible as reference-material. An 'individual worker or an established researcher may retain his types during his period of study but must ensure that the types of his published species etc., are deposited as early as possible to any authorised custodial concern of national importance concern in out country for custody of animal types.

It is desirable that in case a worker has several paratypes and additional specimens of his new species, he distributes these as duplicates to other custodial centres including such reputed ones abroad as the British Museum of Natural History, the U.S. National Museum, Bernice P. Bishop Museum (Hawaii), Australian National Insect Collection (Conberra) etc.

(VI) Merits and Demerits of Type Concept and Typification : The subject and its working, in point, have rationalised the handling of specimens of a working taxonomist for a better understanding of the spicics in relation to one another. The Type concept is a sound scientific concept that projects the naturally occurring speciation system from taxonomisc view point in a cogently illustrated manner.

The onset of typification in taxonomic work has made it obligatory for a taxonomist to leave behind the basis of his observations and inferences for any future comparison and evaluation directly and in a stark manner. The system's value is understood while confirming any case of taxonomist identification. If populations of a species, of considerable variation, abundance and wide distribution range become unavoidably divisible into more than one species on critical studies by revisers and other experts, the existing species with its category of populations is 'represented' by the type specimen of that species already to recognised. For newer species having respective section(s) of specimens of the original species (species *in lato*), respective types are determined afresh and in reference to the type specimen already in existence *i.e.,* the holotype of the original species.

The only **demerit** of the subject of type concept and typification is perhaps the intense fabrication of the number of credited types that grew up at one stage during last 70 years' tenure of the subject. Of course, many of those have been subsequently abolished simplifying the whole thing as an easily workable system.

The other drawback which some point out is the expensive procedure in preservation and continued maintenance for extended duration. Dry state preservation of insects like butterflies, beetles and dipterous ones are to be preserved in constant temperature, pollution free sterilized rooms in equally sophisticated containers which also involves quite a number of technical persons. Even then, quality of material deteriorate and a preserved specimen becomes unfit for any study. As type samples attain such state, they need to be sorted out and replaced by appropriate duplicates in the form of secondary or tertiary types. This limitation forces a custody centre to limit its stock of types etc. The need for 'everlasting' preservation and availability of a type is always there but technically that is not feasible. Moreover, the quality of a material deteriorates though very slowly with time. Reliable duplicates to occupy the place of work out types cannot be made in all cases keeping the lacuna of typification to that extent at least yet a matter of fact for the subject.

(VII) Concluding observation : (i) Typification, (the type concept of animal classification in action and actual practice) while describing new species or any infra or supra-species taxon out of samples of collections or in a revisionary work gives us the properly labelled type specimens etc., which are invaluable and essential as reference material being the properties science. Type material plays a role in taxonomy fixing the meaning of a specific name and are invaluable additions for a museum which preserve them as long as possible and later on arranges replacements as the need arises [The British Museum of Natural History, London, has a gross total of 22 million specimens of which a total of 2,50,000 are the **primary types.**]

(ii) The Type concept and Typification made out of that concept is a basic step in taxonomic thought, the action being an important feature of the code of Nomenclature. Type status given to select samples must be followed with care and in determining and establishing types, the following features must be covered —

(a) full description of types, their illustrations and results on observation and experimentation with them must be published.

(b) full data on types regarding their collection, processing, place of preservation etc. must be published also along with the details outlined above (a).

(c) preservation of types must be made with recognised depositories and such whence those may be obtained by future workers for their consultation.

(d) while describing types, they must be compared with comparable samples of other species and relationship must be clearly stated alongwith reasons for establishing new species by the describer.

(e) The worker establishing a new species or other new taxon status must follow the rules of ICZN, and if necessary will contact the Commission on ICNZ.

Deviation from any of the above dishonours the concept of type status much to the detriment of the quality of Taxonomy as a subject for establling its progress.

4.5 International code of zoological nomenclature (ICNZ)—Its operative principles, interpretation and application of important rules, zoological nomenclature, formation of scientific names of various taxa

From a perusal of this section we may known how a system for classifying animals and naming the various units from highest to lowest level and perfected through decades of thinking and contributions along scientific lines and how the system administered by an International body was made universally acceptable for all working to ascertain the systematic position and scientific name/s of animal/s of their concern.

The International boidy in point are like (i) International Zoological congress which elects a judicial body named (ii) International Commission on Zoological Nomenclature

Classificatory or naming problems must be referred to the Commission for a finalisation. The ICZN (= International Code on Zoological Nomenclature) formulated by the commission gives the regulatory guidelines for working and understanding animal taxonomy and all these are discussed in pages to follow under such break—ups and framework as outlined below :—

- Introduction
- Definition and Basic Features of ICZN
- Brief History of ICZN
- Operative Principles and other Features of ICZN (Interpretation and Application of rules, Formation of scientific names/Zoological Nomenclature).

(A) **Introduction :** Nomenclature (names=name; calare = to call, L.,) literally means, to call by name(s). Critically it means, allocation of names of to the biological taxa as per nocus of the concerned International Code (here, Zoological code), the purpose being to provide a designation that will mean the same thing to all people of all nations through all foreseeable time. A correct and fixed nomenclature is an imperative to all truly scientific investigation and discussion. Even the most primitive natives knew living beings of their surroundings by names. But such names and local names in different languages in different countries lack clearly in having (i) any classificatory value and (ii) international communicability, in spite of their having a limited advantage as a means of ready reference. The science of zoological nomenclature tries to avoid ambiguity and inconsistence providing suitable **lables** to the organisms at all classificatoty **lavels** ensuring an error-free, unique and stable means to comminicate correctly and internationally abnout them for all time to come. As such, zoological names are unimportant; they gain importance because they are useful and scientific reference to such "name—bearers" is not possible without using those names.

(B) **Definition and basic features :** Zoological Nomenclature is mainly the Bionomial System of Nomenclature, as applied to a species of animals for the first time, by Linnaeus (Karlvon Linne, the Swedish Naturalist of 17th century). A species is designated by a combination of its specific and generic names thus having the need of two names to be called in a scientific names which as thus a binomial system.

In the lenth edition of this teratise, **systema natural**, of Linnaeus, and following this, the first date of January 1758 was accepted both as the date of publication and the starting point of the binomial naming system for animals (**only exception** : nomenclature of spiders that starts from 1757 A.D.)

In strict sense, the term **binomial** is not valid though it replaced the original term **binary** during the past-Linnaean era. Since 1961, the term **bionomial** has been replaced by the term binomial (originating from the latin term **binomen**) and hence, in spite of the erroneous usage still persisting, the Linnaeus' binomial nomenclature should be correctly referred to as **binominal nomenclature**.

The International Code of Zoological Nomenclature (i.e. The ICZN) applies both to the living and the extinct animals, including the animal-like Protista (Protozoa). It regulates the names from family level down to subspecies level; names above family level are not yet within its formal ambit. The baisc principles of the code are to ensure that (i) any given taxonomic grouping of a given rank can have only the correct name, and (ii) stability in the naming and classification of organisms.

The ICZN consists of three main parts : (i) The code Proper, (ii) The Appendices, and (iii) The Glossary. The Code proper includes a preamble followed by 87 articles which are composed of mandatory rules devoid of any explanation and told in starkly concise words. There are recommendations in some cases but those are not mandatory. The appendices, like the recommendations, need not be strictly followed. The Glossary contains the pointed definition of the terms used in the code.

(C) Brief History of ICZN : The early naturalists used scientific names according to their personal preferences. Some tried to use the names devised by others. Some worked without any library facility or paid scant attention to what others did or were doing. Some accepted the authority of leading naturalists and rejected others totally. As a result, many species and genera were given different names by different workers to entirely different animals. Linnaeus himself was the 'Father' of a set of rules of nomenclature published in his **Critica Botanica** (1737) and **Phisophica Botanica** (1751). His authority waned in nineteenth century and was replaced by various loval rules causing confustion. To stop it, Zoologists of the western countries drafted formal rules and principles of nomenclature. Those were adopted as an International code at the Fifteenth Zoological Gongress held in Berlin in 1901. As a code, however, the subject was formulla issued after the sixth Congress. The code countinued to be rectified with each congress till at the Fifteenth Congress held in London in 1958, a new version of the code was adopted and issued. That formed the guiding reference till now with additions or alterations of a minor nature from time to time being officially operative with effect from the sixth day of November, 1961 (the Code's updated version, however, was made available only in 1964).

The International Zoological Congresses are the legislative bodies so for the codes of Nomenclature are concerned. They elect the International Commission on Zooligical Nomenclature, a judicial body on a permanent basis, to interprete or suspend the provisions of the code in individual cases and to submit to the Congress the recommendations for the classification or modification of the code. The Division of Zoological Sciences, or the General Assembly of the International Union of Biological Sciences are the recognised equivalents of the International Congress of Zoology.

For nomenclatural problmes on animals, nay Zoologist may submit cases to the Commission but he/she must not use, his/her contentions till the Commission judged those and got those approved by the Congress or its counterparts. The commossion maintains the official lists of family, genus and species names in Zoology, the official indices of rejected and invalid names etc. anyone can have access to these documents of Commission on suitable notification to it.

(D) Operative Principles and other features of ICZN :

(1) Framing a name (Uni., Bi-, Tri-nominalism etc.) : Naming of a species taxon is done by two words (binomen) of any taxon above species i.e., for any macrotaxonomic unit, is by one word (uninomen). To write a zoological (= scientific) name down to subspecies, one has to use three words (trinomen) and if a subgenus name is included, the name becomes a 4-word name (quadrinomen).

Full citation of a sc. name in any critical writing consists of all parts of the above as available and always the surnames of the author of the species (i) though in routine citation, the same is excluded (ii-iii) as shown below :

Name/Status	Genus	Subgenus	Species	Subspecies	Author
(i) *Firstly*	*Dacus*	(*Afrodacus*)	*aberrans*	*nigritus*	Hardy
(ii) Indian tiget	*Panthera*		*tigries*	*tigris*	—
(iii) Modern man	*Homo*		*sapiens*	*sapiens*	—

Workers in taxonomy prefer also to write the year when the species is established by its author Hardy (done as : "... Hardy, 1934").

No punctuation mark is used from one to other end of the name, but if any worker's name other than that of the author (the first describer of the species) needs to be mentioned in any particular case, the same may be written by putting punctuation mark (; / :) after the species name. Similarly, no diacritic mark (ü), apostrophe (s') hypen (-) etc., should be used in a sc. name [müllcri is written as mülleri, d'urviellei as durvielled]. Use of number in sc. name is also not approved (10-lineate) written as decimiineate).

Abbreviated use of author's name (Linn./L.–for Linnaeus) is not couated as a good practice as per code. Genus to subspecies part of a scientific name is italicised or underlined, if not italicised.

In a two-word/two-part structure of a sc. nane for which it is called as Binomial System of Nomenclature, the first word/part denotes genus name ans second word/part denotes species name. First alphabet of genus name is always in capital/block letters while the other alphabets of genus name and all of species name are in small letters (for a species name made after a country/locality i.e., for a geographical sc. name the first alphabet of species part may also be written in capital letter e.g. *Culicoides Calcuttensis*), instead of the usual small letter.

(2) Basic language of scientific names : Latin or latinished form of words or other languages if used (Latin was the **lingua franca** of the educated people of western countries when animal taxonomy in present sc. from developed, and once started as the medium for sc. names, the same cannot be altered).

All taxonomic names are unique, i.e., same name not applicable more than once under a taxonomic state (species/genus etc.). Species names ordinarily are based on any of its characteristic features, morphological or otherwise. /any such name must be adjective form in nominative singular agreeing in gender with genus name which is in noun form; examples—

Ending-in species name	**in genus name**	**** Name in full to exemplify**
feminine ending (–a/–e)	(–a/–e)	*Dasyhelea setigera***
neuter ending (–um/–us etc.)	(–um/–us etc.)	*Plasmodium falciparum*
masculine ending (–i)	(–i/–us/–es)	*Anopheles stephensi***
(generally for patronyms)		

(** all are blood-sucking dipterous insects)

The compatibility/suitability factor involving genus and species parts of a scientific name is, however, inoperative once a name is framed and published (a butterfly species having long tails if published as **brevicauda** or the vice-versa, then it cannot be changed.).

Similarly, a geographic name is framedto indicate that the species either is dominant in its name-locality or restricted to that only; if subsequent studies prove its distribution otherwise, the name in use being published already cannot be changed though it now contradicts its factual prosition in nature.

(3) In all codes, some provisions exist for regulating naming of suprageneric taxa Zoological Code only deals with taxa from superfamily to tribe andtherulesandthe practices in this respect lay down that the endings of such names should be framed conforming to following (Macrotaxonomic names, taxa above family, lie outside code's provisions as a rule, in deposits) :

Taxon Level (T.L.) Ending of the name :—

Superfamily	...	*oidea*
Family	...	*idae*
Subfamily	...	*inae*
Tribe	...	*ini*
Subtrive	...	*ina*

(4) **Rules on Priority/Law of Priority :** A search through taxonomic literature specially through the species or the genus catalogues of different animals of different zoogeographical areas may reveal the following anomalous instances :

(a) **Cases of Synonymy :** It so happens sometimes that the different species names are applied to such sets of animal populations that are actually conspecific. This is due to the fact that the concerned taxonomists fail/s to appreciate correctly the status of the animal populations involved in his/their studies and take/s them as new to science ignoring the conspecificity of the species with the known, related ones. The case of synonymy however persists and subsequent, revising worker/s correct/s the situation by holding the synonymous species, described earliest of all such species, as the **Senior Synonym** and the Valid Species while sinking down the remaining species as the **Junior synonyms** and the **Invalid Species.** No change of authorship of the species name is permitted in any case or homonymous revision and correction. Another provision is that the various synonyms are replaced by the senior synonym i.e., the name in synonym-cluster published first provided the junior synonym has not been in use for more than 50 years. Judged from other viewpoints, the synonymy may also be divided into following two types :

(i) **Subjective Synonymy** (also called, Taxonomic Synonymy, or Heterotypic Synonymy) : These are based upon different types and they remain synonyms only as long as their respective types belong the the same taxon. The synonymy in such cases is not absolute and hence it is indicated by the mathematical sigh of equality (=)

(ii) **Objective Synonymy** (also called **Nomenclatural Synonymy,** or **Obligate Synonymy,** or **Homotypic Synonymy) :** These are based upon same type and hence, these are always absolute, such a synonymy is indicated by the mathematical sign of congruence ($\equiv$).

The synonyms of any kind, however, pose great problems for the taxonomists. A great significance follows them since they provide considerable information. It is not easy to establish them as the work needs high level thoroughness and expertise.

[*egs.* (a). Some 251 species of **Anodonta** (Fresh-water Mussel) from France, were subsequently found by the experts to be the mere habitat-variants (the Junior Synonyms) of 2 valid species of the genus.

(b) The instances involving the blood-sucking biting midge insect ***Culicoides schultzei*** (Enderlein) illustrate the cases of subjective *synonymy* more aptly. This variable and widely abundant species was first described from Africa. Subsequently, over years, its existence was recorded from different parts of Asia covering such diverse countries as Iran, Iraq, Israel, India, Pakistan, Sri Lanka to China and the Asian parts of the U.S.S.R. its amazing array of morphotaxonomic variability led the working taxonomists indifferent countries to call the populations concerned in their area by different scientific names trating each as a distinct species. Critical studies covering all such species later on concluded the following —

Culicoides schultzei (Enderlein), 1908, is the Senior Synonym and hence the valid speices; the following are conspecific to it and hence sunk as its Junior Synonyms :

(i) ***C. kingi*** Austen, 1912 ... described from Africa

(ii) ***C. mesopotamiensis*** Patton, 1920 ... described from Africa

(iii) ***C. oxystoma*** Kieffer, 1920 described from India

(iv) ***C. kiefferi*** Patton, 1913 1920 described from India

(v) **C. alatus** Dasgupta & Ghosh, 1956 described from India

(vi) ***C. housei*** Causey, 1938 described from Thailand

(vii) ***C. punctigerus*** Tokunaga, 1950 described from Indonesia

A more recent study treats the above complex divisible into two distinct species—the African ***C. schultzei*** (other African spp. being its junior synonyms) and the Australo-Asian *C. oxystoma* (other Asian spp., being its junior synonyms).]

(b) Case of Homonymy : It may be detected by a reviser that a particular species name has been used by a describer to describe his new species in a genus being unaware, through mistake or insufficiencieson his part, that the said species name was already used by some previous worker to describe the worker's newly found species of that very genus, i.e., the species name in the genus was preocupied. This forms the case of homonymy and it requires correction as two different species of a genus cannot be called by the same name though their authors are different. Thus, *the homonyms are the scientific names of animals which are spelt in a similar manner (i.e., those names have identity in spelling) or in a way so similar as to be treated identical as per the Zoological Code though the taxon levels of the animals are based on different types.*

The reviser dealing a case of homonymy corrects the anomaly by retaining the case described earliest (the Senior Homonym) as it is but he alters the species name of the other concerned (The Junior Homonym/s) in his own free way and the authorship of the species whose name is thus altered (= newly named species, i.e., species nomen novum, or, sp.n.n.) now belonged to the reviser. Sen and Dasgupta (1958) detected a case of homonymy involving two species of biting midge insects of the genus *Culicoides* as follows :

(i) *C. orientalis* Macfie, 1932, the Senior Homonym, described on samples collected from different parts of Southeast Asia, including India;

(ii) *C. orientalis* Gutsevich, 1956, the Junior Homonym, described on samples collected from the Asiatic parts of the former Soviet Union.

The taxonomic separateness of the populations of macfie's species from those of Gutsevich's species was clear and the situation was corrected by Sen and Dasgupta (1958) by renaming the latter's species (the Junior Synonym) in honour of him, the patronym thus framed being *C. gutsevichi* Sen and Dasgupta, *nomen novum, i.e.*, new name, for *C. orientalis* Gutsevich.

(c) Primary Homonyms and Secondary Homonyms : In the example of a homonymy involving biting midges, cited above, the homonym cluster of the two identical species names belonged to the same nominal genus. Such cases form the Primary Homonym Cluster or simply, the Primary Homonyms as these involve a single genus i.e., the genus taxon is common to the homonymous species from beginning. Another example of the Primary Homonym Cluster is :

(i) *Rana tigrina* Linnaeus,, 1758—the Senior Homonym;

(ii) *Rana tigrina* Fabricius, 1795—the Junior Homonym.

The Junior homonym *tigrina* Fabricius is invalid and it is replaced by a new name.

Now, if in a homonym cluster, any one of the names originally is in a different genus but shares the common genus creating the problem of homonymy due to its subsequent shift from its original genus to the common genus, the cluster in view forms the Secondary Homonym Cluster or simply, the Secondary Homonyms.

[egs. (i) A case involving earwigs, the insects of the order dermaptera, is as follows : *Forficula riparia* Dufour, 1805, is reassessed by Bolivar (1897) who finds that the species actually belongs to the genus *Labidura*. He therefore enacts the the generic shift due and the species henceforth is 'correctly' written as *Labidura riparia* (Dufour). But a problem of homonymy arises as there already existed a valid earwig species named *Labidura riparia* Pallas, 1790. It was obvious that the case was one of Secondary Homonym Cluster, and *L. riparia* Pallas was the Senior Homonym while *L-riparia* (Dufour) was the Junior Homonym. The correction was instantly made by Bolivar (op.cit.) who changed the name of the Junior hononym as *L. indians* Boliver.]

(ii) In determining the junior/senior status in a case of Secondary Homonymy, the year of original description of the species counts, Notwithstanding if its status is correct from the beginning. A species described earlier in a wrong genus and corrected genuswise at a data to that of the description of the species with which it forms the homonym cluster is taken as the senior homonym. It needs no change in its species part, but the other species being the Junior homonym undergoes change of name in its specific part.

Caratopogon falcatus Meunier, 1904, was corrected by Szadziawski (1988) as *Stilobezzia falcate* (Meunier), new combination, while earlier, Chaudhuri *et al.* (1974) described a new Indian species as, *S. falcata*. As per rules governing Secondary Homonomy, *S. falcate* (Mouriar) is the senior Homonym and after its creatinby intergeneric shuffling, Choudhuri *et al.* changed their species patronymically and as : *S. szadziewskii* Choudhuri *et al.* 1990).

(d) Merits and Demerits : The Law of Priority in Zoological Nomenclature is also used to tackle problems as explained above at super-species and higher levels.Though its application may generate controversy among the taxonomists, it is a basic law of International Code to promote stability. Whenever a case showing two or more names of the same taxon is detected or it is seen that the case is the other way round, the problem of validity of one is settled by this law. Its only drawback, however, is that under cover of this law, even the names poorly and incompletely described originally become valid because those are oldest. In other faculties of science, there is no such provision for valuing any work that is not preciseor complete, and those are simply ignored. Of course, the requirements and peculiarities of different faculties need not be the same. Thus, Priority Rules form a somewhat controversial part though essential of the zoological code. A zoological name must be "available" in the first instance being published as per the relevant clauses of the code. The name of a taxon is "valid if it is the oldest available name applied to ..." the taxon. Date of publication of a name is thus very important.

Priority means Priority of Publication, not priority of usage.

Law of Priority in Zoological Nomenclature applies only to the categorical levels of species (and subspecies), genus and family but not to higher categories.

(5) Rule of New Combination : If a described species is found placed in a wrong genus either through an initial error of generic misidentification or through any subsequent shift in the generic conception, an intergeneric transfer of the species becomes necessary. The name of the original author of the species that forms a part of the scientific name ofthe species is now kept in parentheses (a set of first brackets) in the corrected from of the name, with the name of the original author in parentheses, is called the *new combination name*. The year of the original author first describing the species may also be cited as also the name of the reviser who affected the New Combination, together with the year of his doing so. Some commonplace examples of writing the New Combinatin names, showing part or full details, are as follows :

(i) Indian lion, correctly written as,

Panthera leo (Linnaeus), New Combination,

(ii) Flatworm *Taenia dminuta* Rudolphi, after the required intergeneric correction, is written as,

Hymenolepis diminuta (Rudolphi), New Combination

(iii) Fruitfly species *bipars* Walker, 1862, after correction, is written as, *Hemilea bipars.* (Walker, 1862), Hardy, 1959, New Combination.

It is obvious that in all three cases as above and in similar cases, every species historically has double names—one, the original scientific name given by the first describer (egs. *Sophira bipars* Walker, for fruit fly, *Taenia diminuta* Rudolphi, for the flatworm etc.) and this original name of the species is called as its *Basionym*; the other name of the species is the corrected scientific name (eg. *Hemilea bipars*) (Walker), for the fruit fly in point), the *New Combination name* of the species.

Patronyms : The scientific name whose species part is framed by latinising a geographic location name (after which the species is named) or the surname part of the name of a person (after whom it is named)is a patronym. Such a dedicational name after a localityis assigned to indicate that the species so named is endomic or common to that locality, while after a person, to recognise the fame/contribution/involvement of the intended person direct or indirect, with the subject of study of the framer of the name, or sometimes simply to prtpetusto the memory or a person whom the framer ofthe name may hold in personal effection or storm. As a rule, the surname part (modern family name) of the whole name of a person in view is used. It is suitably latinised by just adding the alphabet 'i' at its end if the person is male and adding the alphabet 'ae' at its and if the person is female.

Examples : *Culicoides wirthi* is the name given to a Nearctic species of *Culicoides* insects, dedicating th species part after the surname of the famed American Dipterist Dr. W. W. Wirth, for his monumental contrinution on those insects. Earlier, Dr. Wirth dedicated a new species of genus Stilbezzia biting midyes from Virginia, USA; in remembrance of untiring help of his wife Mrs. Austin Syble Wirth, he named it after her as *Stilobezzia (Stilobezzia) sybleae.*

(6) Other provisions

(a) Use of Square Bracket : The citation of the name of the author of a species in square brackets, [...], means that the said author's name has been taken from any indirect source because of the original anonymity.

The square breakets are also used to include statement of misidentification.

(b) Names given to hybrids : Hybrids are normally individuals, not populations,and hence are not taxa. A name given to an animal which later onis found to be a hybrid is a *nomal hybridum*, available for a limited use only—it is not applicable to either of the parental species, not applicable for purpose of synonymy as well; it is usable only for purpose of homonymy.

(c) Protection of well-established names : A valid sc.name if not inuse forover 50 years at a stretch in literature but is referred to by any of itsjunior synonyms consistantly, then as per a provision of the Code, the unused valid and senior name becomes a nomen oblitum (i.e., obliterated name) and its junior name in maximum use becomes the official name for the cluster involved.

(d) Miscellaneous : A genus name is uninominal; so are the names of of taxa above genus rank being however in plural (expressions thatwe commonly do such as, The Culicidae is the dipterous family that includes all mosquitoes, is not correct; we are to say, The culicidae are the ...

A family name should be based on the valid type-genus name.

New species are to be indicated in the first or original description by writing, sp. n., or sp.nov., or spec. nov. (in each case being the abbreviation for species *nouvelle* i.e., new species) after the full name of such a species or by writing full species name followed by the surname/s of author/s of that speices and than putting the words n.sp./ new species (meaning just new species) after a coma-punctuation (,)., or not. examples are :

(i) *Culicoides oxystoma* n.sp.

(ii) *Culicoides oxystoma* Kieffer, sp.n.

(iii) *Culicoides oxystoma* Kieffer,

(iv) *Culicoides oxystoma* sp. nov.

(v) *Culicoides oxystoma* Kieffer, new species

(vi) *Culicoides oxystoma* Kieffer, n.sp.

(vii) *Culicoides oxystoma* spec. nov. ... etc.

Similar provisions also exist for describing other taxon units (gen. nov. for genus etc.)

(e) General remarks : The Linnean System of Binomial Nomeclature is a compromise of the Aristotlian logic and a simple informaiton retrieval system.

The principles perfected so far for this system have helped us to refer to animal populations as per the ways of science. But diversities in the animal groups are so many that quite often, the different groups cannot be tackled satisfactorily. Then, there exists the eternal confusion amongst the various taxonomic school—the conflict of the 'Lumpers' and the 'Splitters', extended lists of the animal taxa reduced to smaller ones by the yardsticks of the former which the latter category of workers are unable to support!

The simplification of the principles guiding to frame the binomial names is also in point. A generic name no longer tells us much about the organism concerned. The worst aspect is the extreme instability of the system itself. The original Linnaean way was generic name + *differentia, i.e.,* species name given in several words explaining in brief the characters of the species, and it was inherent that a change at one point in the system sets in a number of changes as a whole. This is a serious drawback as genera are split or lumped and the species are frequently shifted from one genus to the other. Such changes reduce the practical efficiency of the binomial system, as a reference system, and suggestions are made from time to replace it as follows :

(i) addition of prefixes and suffixes to generic names to indicate class, order etc. Eg. **Papilio** (a butterfly genus) recommended to be written as **YIP apila,** where Y = Insecta, I = Lepidoptera, and a = Invertebrata!

(ii) Michener (1964) favours replacement of binominalism by uninominalism or mononominalism. He proposes freezing of original scientific name of a new species for all times by connecting generic and specific name with a hyphen, Eg. *Homo sapiens*, recommended to be made uninomen and written as, *Homo-sapiens*. This has superficial advantages as problems of homonymy willendings to agree with the gender of the genus-name. But, this may create confusion when transfer of one species from one genus to another becomes unavoidable (e.g. bee species **jenseni** first placed in genus **nomia** in the family Halictidae, but now it is placed in genus **Leioproctus** in the family Colletidae). Such a change cannot be adjusted as per Michener's proposal.

(iii) According to Griffiths (1976), the binomial nomenclature is there to stay since species are far too numerous for uninominal specific nomenclature to be practicable. He suggests that the first (the Generic) name in *Binomina* be called the forename (latin : Praenomen), to avoid the essentialist connotations of the term generic, and fresh conventions for choosing forenames be established.

(iv) The adoption of a numerical scheme for the hierarchy in classification, replacing the *binomen* system by a running identification number, is advocated by Hall (1966), Bullis and Roe (1967) and their followers. The numbering is to be done in a Central International Office.

As per this formulation of Numerical Taxonomy, all species described in 1968 will be called as (from the very first species described as new in that year irrespective of the animal group on a global basis) : 968-1, 968-2, 968-3 etc.

(v) Henning (1969) advocates a scheme of unclassified hierarchy for fossil insects by appending a numerical indication of the subordination sequence. Analysing the phylogeny of 6 fossil species of Mecoptera insects, the names of those soecies are given as : a (1-3), b (2-3), c (3.4), d (4-5) and f (5-7), in numerical sequence.

With a rising need for easy information retrieval and easy programming for computers, there is little doubt that the taxonomists may need to adopt some other system sooner or later. The old binomial system will stay side by side with this system for sometime and may finally get totally replaced. However, of what have been suggested so for, the binomial system is found to be the most satisfactory one since all the numerical systems contrived fail to cope fully with the subtlities produced by the continuous discovery of new taxa in different parts of the world and the resultant shifts in classification. The binomial system reflects classification of the species taxon in its proper perspective. It shows that one taxon is a member of a next higher taxon. When the classification of a group is well advanced and the genera are trully the natural units, the binomial system can form excellent basis for prediction of phylogenetic, evolutionary and zoogeographical speculation, other systems have hardly such in-built scopes and provisions.

UNIT 5 □ The Meanings of Biodiversity

Structure

5.1 Introduction

5.2 Levels of biodiversity

5.3 The regional / historical perspective on species richness

5.4 Local and regional components of diversity

5.5 Ecosystem diversity

5.1 Introduction

Biodiversity is the variety and variability of plant and animal species on our planet. There is a distinction between biological resources and biological diversity. The part of the biological diversity, which are used, or potentially to be used by human civilization is considered as biological resource.

In 1735, Carolus Linnaeus, published a book on the classification of plant and animal species. He proposed a hierarchy of classification, from species through genus, family, order, class, phylum and kingdoms, into which all plant and animal species would fall. The first edition was only 142 pages long but the sixteenth edition was over 2300 pages, as Linnaeus was flooded with information from all over the world. The Linnaean system has come to form a basic tool of biological science. We have, of course, made great progress in understanding the biology of the world in the last two centuries. Concern over the rate of loss of the plant and animal species on our planet has been growing for some years.

Extinction has always been a fact of life. But the intervention of humans has injected a novel thrust into its causes. A large array of impacts has been brought to bear, including over-exploitation, habitat destruction, introduction of exotic pest species and current spurt in various forms of pollution. Therefore, the loss of Biodiversity should be of concern to every one for at least three reasons : First, we have a moral responsibility to protect what are our only known living companions in the universe. Second, humanity has already obtained enormous benefits from biodiversity in the form of foods, medicines, and industrial productions and has the potential to gain many more benefits. Thirdly biodiversity provides essential ecological services to mankind by maintaining the stability of its environment. Not surprising conservation of the world's remaining species has come to assume great importance in the present times.

Biodiversity is the variety of life. The concept of biodiversity includes the entire biological hierarchy from molecules to ecosystems, or the entire taxonomic hierarchy from alleles to kingdoms, all the logical classes in between (individuals, genotypes, population, species etc.), and all of the different members of all those classes. It also includes the diversity of living interactions and processes at all these levels of organization. This is such a wide-ranging description that it has kept the definition of the term "biodiversity" vague and ensured that its measurement remains difficult. For practical purposes we need a much more precise definition. This context is the one in which short term human needs and desires led to broad scale destruction of the biological inheritance of the plant, and in turn gave rise to a movement aimed at protecting that inheritance. This movement has the implicit goal of protecting the variety of life, which is a different goal from the equally legitimate one of preserving particular species. The term "biodiversity" was coined by Walter G Rosen during the organization of the 21-24 September 1986 "National Forum on Bio Diversity" held in Washington DC, under the auspices of the US national academy of science and the Smithsonian Institution (Takacs 1996). The term "biodiversity" found wide use immediately following its coining.

The biological realm-patterns and processes are marked by variability and complexity at every level of organization. It is useful at this stage to distinguish between biological diversity and what has come to be called biological integrity. Integrity refers to the persistence of ecosystem processes such as the generation of biomass or the flow of nutrients and energy within specific bounds. The conservation of biodiversity is presumably related in some way to the maintenance of biological integrity. At one time it was widely believed that complexity of process pathways led to the stability of ecosystems (Mac Arthur 1955; Elton 1958). Since increased diversity at almost any level of biological organization leads to increased complexity and stability presumably implies integrity, such a complexity stability relationship implies a biodiversity integrity relationship. However, there remains little uncontroversial theoretical rationale (May 1973) or empirical results (Pimm 1984, 1991; Shrader-Frechette and Mc Cay 1993) supporting the diversity stability relationship. Nevertheless, it is at last likely that the maintenance of ecosystem processes will contribute to the conservation of biodiversity since it may ensure that all important biological processes persist (Karr 1991; Angermeier and Karr 1994; Margules and pressey 2000).

5.2 Levels of biodiversity

It has become a widespread practice to define biodiversity in terms of genes, species and ecosystems, corresponding to three fundamental and hierarchically - related levels of biological organisation.

Genetic diversity : This represents the heritable variation within and between populations of organisms. Ultimately, this resides in variations in the sequence of the four base pairs which as components of nucleic acids, constitute the genetic code. New genetic variation arises in individuals by gene and chromosome mutations, and in organisms with sexual reproduction can be spread through the population by recombination. Other kinds of genetic diversity can be identified at all levels of organization, including the amount of DNA per cell, and chromosome structure and number.

This pool of genetic variation present within an interbreeding population is acted upon by selection. Differential survival results in changes of the frequency of genes within this pool, and this is equivalent to population evolution. The significance of genetic variation is thus clear that it enables both natural evolutionary change and artificial selective breeding to occur. Only a small fraction (often less than 1%) of the genetic material of higher organisms is outwardly expressed in the form and function of the organism; the purpose of the remaining DNA and the significance of any variation within it is unclear.

Each of the estimated 10' different genes distributed across the world's biota does not make an identical contribution to overall genetic diversity. In particular, those genes which control fundamental biochemical processes are strongly conserved across different taxa and generally show little variation, although such variation that does exist may exert a strong effect on the viability of the organism; the converse is true of other genes.

Species diversity : Because the living world is most widely considered in terms of species, biodiversity is very commonly used as a synonym, of species diversity, in particular of species richness, which is the number of species in a site or habitat. Discussion of global biodiversity is typically presented in terms of global numbers of species in different taxonomic groups. The species level is generally regarded as the most natural one at which to consider whole organism diversity. Species are the primary locus of evolutionary mechanisms, and the origination and extinction of species are the principal agents in governing biological diversity in most senses in which the latter can be defined. On the other hand, species cannot be recognised and enumerated by systematists with total precision, and the concept of what a species is differs considerably between groups of organisms.

Further, a straight forward count of the number of species only provides a partial indication of biological diversity.Organisms which differ widely from each other in some respect by definition contribute more to overall diversity than those which are very similar. A site with many different higher taxa present can be said to possess more taxonomic diversity than another with fewer higher taxa but many more species. Marine habitats frequently have more different phyla but fewer species than terrestrial habitats, *i.e.*, higher taxonomic diversity but lower species diversity. The ecological importance of a species can have a direct effect on community structure, and thus on overall biological diversity.

Between habitat and within habitat diversity : Small uniform habitats must be shared, but relatively large patches of land may be partitioned among species. Mac Arthur (1965) introduced convenient terminology to described these two conditions : "within - habitat diversity" and "between habitat diversity." Earlier Whittaker (1960) had pointed out the same essential dichotomy, calling the two conditions "alpha diversity" and "beta diversity". If animals colonize a large empty habitat with considerable resource plasticity, they will share all parts of the habitat, resulting in an initial within habitat diversity (Alpha diversity). But if more colonizing animals arrive, the greater crowding might will cause the habitat to be divided into subhabitats by species keeping themselves apart. Between habitat diversity (ß diversity) has now been added to the original within habitat diversity.

Cody (1975) extended the classification for bird species diversity to allow comparison among whole geographic regions. "Point diversity" describes the complete overlap of bird ranges over very small areas. "Gamma diversity" describes the species replacements that occur over very large geographic regions. Adding these two concepts results in the following scheme : -

Within habitat	Point diversity	=	Found together in very small samples
	Alpha diversity	=	Found together in small homogeneous habitats
Between habitat	Beta diversity	=	Diversity across a diversity of habitats
	Gamma diversity	=	Regional diversity including geographical replacement.

Contemporary thinking about community organization reconciles the regional historical and local /deterministic views of regulation of diversity :—

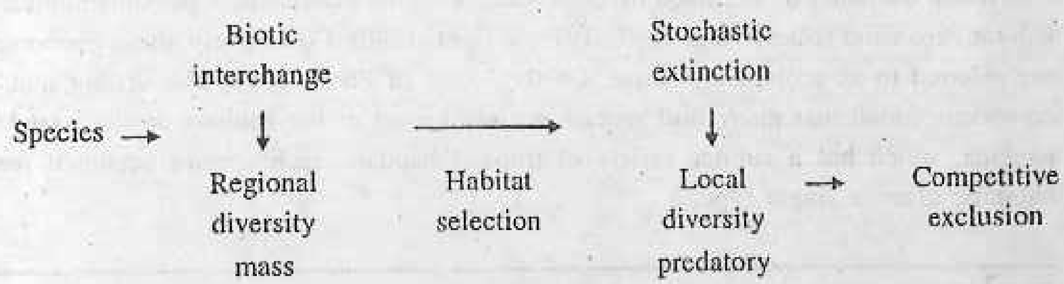
Until the late 1950s, ecologists viewed species diversity as a regional phenomenon representing the outcome of historical events. We shall refer to this view as the regional / historical view of species richness. Subsequently, ecologists began to ask questions about how population interactions such as predation and competition affect species diversity. Fundamental to this local/deterministic view is the idea that local interactions, which tend to reduce diversity through competitive exclusion and extinction, somehow balance regional processes that increase diversity through specialisation and migration, maintaining a kind of equilibrium. Let us examine the local/deterministic and regional /historical views in more detail.

5.3 The regional/historical perspective on species richness

While emphasizing the importance of local population interaction in determining local diversity, ecologists were still faced with the reality of regional processes. Local interections, taking place within a milieu of local conditions, determine the number of the species that can coexist in the local community. This number is the saturation point, beyond which no new species can be added to the community. Regional processes, such as species production, migration, and historical accidents of geographic location, determine regional diversity. The difference between the two is accommodated by difference in the degree of habitat specialization, or beta diversity which is adjusted to maintain the number of species locally in accordance with local conditions while the number of species in the region may vary.

5.4 Local and regional components of diversity

Local and regional factors are expressed in different components of species diversity, two of which are alpha (or local) diversity and gamma (or regional) diversity (Whittaker 1972). Local diversity is the number of species in a small area of more or less uniform habitat clearly.



Local diversity is sensitive to definition of habitat, area, and intensity of sampling effort. Regional diversity is the total number of species observed in all habitats within a region. By region, ecologists generally mean a geographic area that includes no significant barriers to dispersal of organisms. Thus, the boundaries of a region depend on which organisms we consider. The important point is that within a region, distributions of species should reflect their selection of suitable habitats rather than their inability to disperse to a particular locality.

When each species occurs in all habitats within a region, local and regional diversities are the same. When each habitat has a unique flora and fauna, regional diversity equals the average local diversity times the number of habitats in the region . Ecologists refer to the difference, in species from one habitat to the next as beta diversity. The greater the difference, or turnover, of species between habitats, the greater the beta diversity. There are many different ways of quantifying beta diversity, but a useful one is the number of unique habitats recognized by species within a region. When all species are habitat generalists, there is effectively only a single habitat within the region, and beta diversity is equal to 1. As habitat specialization increases, more habitats are recognized. Accordingly, gamma diversity equals alpha diversity X beta diversity. It is not practical to measure beta diversity directly because the habitat distributions of species overlap. But we can calculate the number of unique habitats recognized by species within a region from the relationship, beta diversity = gamma diversity/alpha diversity.

Where many species coexist within a region, each occurs in relatively few kinds of habitats (Mac Arthur *et al.*, 1966). Changes in gamma diversity generally result from parallel changes in both alpha and beta diversity. This relationship has been most carefully noted in comparisons of islands and mainland regions, in which one may examine a range of species diversity resulting from different degrees of geographic isolation within similar ranges of physical conditions. Islands usually have fewer species than comparable mainland areas. Island species often attain greater densities than their mainland counterparts, a phenomenon called density compensation (Crowell, 1962). Also they expand into habitats that would normally be occupied by other species on the mainlands, a phenomenon called habitat expansion (Mac Arthur *et al.*, 1972, Wright ,1980). Collectively, these phenomena are referred to as ecological release. On the island of Puerto Rico, Mac Arthur and his coworkers found that many bird species occupied most of the habitats on the island. In panama, which has a similar variety of tropical habitats, each species occupied fewer habitats, often a single type.

5.5 Ecosystem diversity

It is possible to define what is in principle meant by genetic and species diversity, and to produce various measures thereof, there is no unique definition and classification of ecosystems at the global level, and it is thus difficult in practice to assess ecosystem diversity other than on a local or regional basis and then only largely in terms of vegetation. Ecosystems further differ from genes and species in that they explicitly include abiotic components, being partly determined by soil parent material and climate. Ecosystem diversity is often evaluated through measures of the diversity of the component species. This may involve assessment of the relative abundance of different species as well as consideration of the types of species. In the first instance, the more equally abundant different species are, then in general the more diverse that area or habitat is considered to be. Weight is also given to the numbers of species in different size classes, at different tropic levels, or in different taxonomic groups. Thus, a hypothetical ecosystem, which consisted only of several species of plants, would be less diverse than one with the same number of species but which included animals herbivores and predators.

UNIT 6 □ The Value of Biodiversity

The value of biodiversity is difficult to define, and is often impossible to estimate. Although biodiversity rarely has a money price in local or international markets, its economic value is wide-ranging and significant. Economists recognize two main types of value : use values and non-use values. Use values refer to the current or future utilitarian value of biodiversity to humankind, and can in turn be sub-divided into direct, indirect, and option values. Examples include the use of wild genes in crop breeding, the tourism value of game reserve, or the ecosystem services of a unique wetland habitat. Non use values refer to the intrinsic, vicarious values attached by individuals to, for example, the continued existence of a particularly "charismatic" species such as the African elephant. These various types of value are shown in table 1 below.

The direct use value of biodiversity can be further sub divided into three categories consumptive, productive and non-consumptive. The main difference between consumptive and productive value is that the former is consumed directly without being traded. This makes valuation more difficult, and may involve a wider range of goods, but is not otherwise of major significance.

Biodiversity confers direct use value in at least three areas : agriculture, medicine and industry. The benefits of biodiversity in agriculture include new crops, diverse traditional farming systems, and improved varieties of existing crops and new pesticides. The introduction of new crops has a massive economic impact in the past (98% of US crop production is based on species originating outside its borders). New products such as the Kiwi fruit from China, continue to be important. It is nevertheless instructive to note that less than, 20 species of the thousands of edible plants known to exist produce most of the worlds food. Three species-wheat, maize and rice-account for 54% of the calorific consumption in developing countries. This demonstrates the important point that economic growth in agriculture is best served by concentrating on a reduced range of species (and a reduced range of varieties). Recent claims that multi-species extractive forest systems give higher financial returns than timber and agriculture need to be assessed critically in this light. The main reasons why diverse extractive systems and subsistence agricultural systems are replaced by more specialized agro-ecosystems is because they are inherently less productive. The important qualification to this is that even specialized agro-ecosystems benefit from local habitat diversity (wild pollinators, natural predators etc.) and from management which maintains diversity, such as crop rotation.

While the exploitation of a diverse range of species may have long run economic cost, genetic diversity is more clearly beneficial. Whether bred into advanced agrosystems, or inherent in transitional one, genetic diversity has considerable economic value. In uncontrolled environments and with low technology levels, genetically diverse traditional agricultural systems exhibit greater stability in the face of climatic, pest and disease risks. Production in any one year might be higher if a smaller range of species and genes was utilized, but the long run average production and/or the minimum production in a particularly bad year, is higher if a wider range is utilized. Traditional technologies are more stable and sustainable than, for example, genetically narrow green revolution technologies, but are also considerably less productive, 1987). Few seriously question the value of replacing local varieties with high yielding varieties.

Genetic diversity will remain extremely important in the future because of the increasing genetic uniformity, and therefore vulnerability, of improved varieties. These have a finite life, and require periodic infusions of new genetic material if pest and disease resistance is to be maintained. New biotechnological techniques can be expected to increase the use of wild germplasm in breeding programmes. The threat presented by global climatic change also requires that the maximum biodiversity be retained, and also that access to important genetic resources in the transition zones is protected. Maintaining the flexibility to respond to climatic change will be an important benefit. With developing country agriculture increasingly vulnerable, the conservation of local lands and wild relatives of economic crops and livestock is of overriding importance.

In addition to the 20 or so major food crops, between 5,000 and 10,000 plant species provide an important source of food and materials. Examples include timber and fuelwood; root crops; beverage crops; spices; fruits, and fibres. Many of these may currently be only of local importance, but have wider potential. Much less is known about the diversity of these species compared with the major food crops, and very little is being done to conserve them, either *ex situ or in situ*. The value of plant germplasm derived by "genepoor" developed countries from "gene-rich" developing countries has led to demands for free access to all plant resources (including elite breeders' lines) and/or financial compensation. The fact that south-south germplasm flows are probably more important than south north flows has not been fully appreciated.

The consumptive and productive value of medicines directly or indirectly derived from wild species is often cited as one measure of the current, and particularly the future, value of biodiversity. In developing countries up to 80% of the people rely on traditional medicine for their primary health care, most of which involves the use of plant extracts. Around 20,000 plant species are believed to be used medicinally in the third world. Some plant-derived drugs have also proved to be extremely valuable for advanced health care.

One quarter of all prescriptions in developed countries is based on plants, including 21 indispensable mainstream drugs. In addition to current drugs, plants contain complex chemical structures which may never be synthesized in the laboratory, and which might provide important clues for new medicines. One of the more remarkable examples are the so-called vinca alkaloids used in the treatment of childhood leukaemia and Hodgkin's disease. These were developed from an extract of the Madagascar periwinkle (*Catharanthus roseus*) and had a market value to the Drug Company concerned of US$ 100 million in 1985.

The value of medicinal diversity *per se* is less easy to determine. There are real costs, which would follow from the reduction in the diversity of accessible medicinal plants. These would either be the costs of subsequent untreated disease, and/or the additional costs of commercial alternatives. These costs have not been estimated. However, the low current value of patented or unpatented novel chemical compounds—measured in terms of commercial companies' willingness to pay - is indicative of a low market value. Few naturally occurring compounds are marketable without an enormous input of costly research and testing. This accounts for most of the value added in drug development. Undeveloped and untested novel chemical compounds are readily available and very cheap for this reason. This indicates that the value attached by the market to biodiversity at source is low, even though the potential economic value to society may be considerably higher. Similar considerations will apply in the case of traded industrial raw materials. The market value of biodiversity for a developing country is not the total export value of natural products. It is the difference between the discounted present value of the export earnings of diverse export portfolio over time, and the export earnings of a less diverse portfolio. This calculation is not easy to do. As in the case of agriculture, it is likely that the trend towards specialization in line with comparative advantage means that the long —term export value of biodiversity is limited. Diverse habitats and species can also have non-consumptive use-value, such as tourism and scientific research. Tourist revenues are clearly affected by the diversity of species that can be seen, and the range of habitats that can be visited. Species diversity, and particularly the presence of charismatic big game species, is a selling point. However, it is doubtful whether much tourism value can be attached to the vast majority of species, such as the 1 million species of invertebrates, except as part of special ecosystems. No overall valuation of wildlife diversity has ever been attempted. Indirect use values of biodiversity include ecosystem processes only to the extent that these are dependent on species diversity. While the total loss of a unique habitat involves the loss of the ecological processes dependent upon it, the precise effect of a partial reduction in species diversity will vary from site to site. There is, for example, no clear evidence of what effect, if any, the removal of a large percentage of the populations of large whales has had on oceanic ecosystems. Nevertheless, valuable ecological services are provided by certain ecosystems, and attempts have been made to value these services in particular situations. An overall estimation of the value of ecosystem services attributable to biodiversity has never been attempted for obvious reasons Other types of indirect use value - such as the welfare gain from television and other media coverage of aspects of biodiversity - could conceivably be estimated.

The potential value of biodiversity in the future provides one of the main justifications for conservation. Given the immense uncertainly about future values, the option value represents the willingness to pay to retain the option of preserving access to a diverse range of habitats/species/genes. A quasi-option value is the economic value of choosing not to take irreversible steps if new information about alternative outcomes will become available in future. There will certainly be a need for new genetic material to offset new disease or past threats to major food crops. Conservationists also point to the current value of a few naturally occurring compounds, and to the fact that only a fractions of the number of existing species have been assessed for their value to science, agriculture, medicine and industry. Most plant - derived drugs, for example, are obtained from less than 100 of the 250-750,000 species of higher plants in existence. However, the costs of accessing and realizing this genetic potential are immense, and may be prohibitive. Only a small fraction of the number of species existing have ever been screened, and there is evidence that gene banks are already too large and poorly documented to be effectively used.

The final category of value is existence value. These are intrinsic values, unassociated with actual or potential use, which reflect the ability that people receive from simply knowing something exists.The fact that hundreds of thousands of people in developed countries are willing to pay conservation organization to campaign on behalf of endangered species and habitats indicates that people do attach economic value to the existence of some species. There are reasons for thinking that the existence values attached to charismatic species such as whales, elephants and rhinos may not be indicative of existence value more generally. On the other hand, high existence values are attached to habitats even when most of the constituent species are neither known nor valued individually.

UNIT 7 □ Threats to Global Biodiversity

Structure

7.1 Introduction

7.2 Causes of the extinction of biodiversity

7.1 Introduction

Extinction is a natural event and, from a geological perspective, routine. We now know that most species that have ever lived have gone extinct. The average rate over the past 200 million years is 1-2 species per year, and 3-4 families per million year. The average duration of a species is 2-10 million years. There have also been occasional episodes of mass extinction, when many taxa representing a wide array of life forms have gone extinct in the same blink of geological time.

In the modern era, due to human actions, species and ecosystems are threatened with destruction to an extent rarely seen in earth history. Probably only during the handful of mass extinction events have so many species been threatened, in so short a time.

What are these human actions? There are many ways to conceive of these - let's consider two.

First we can attribute the loss of species and ecosystems to the accelerating transforming of the earth by a growing human population. As the human population passes the six billion marks, we have transformed, degraded or destroyed roughly half of the word's forests. We appropriate roughly half of the world's net primary productivity for human use. We appropriate most available fresh water, and we harvest virtually all of the available productivity of the oceans. It is little wonder that species are disappearing and ecosystems are being destroyed.

Second, we can examine following types of human actions that threaten species and ecosystems :

7.2 Causes of the extinction of biodiversity

Over-hunting : Over hunting has been a significant cause of the extinction of hundreds of species and the endangerment of many more, such as whales and many African large mammals. Most extinctions over past several hundred years are mainly due to over-harvesting for food, fashion and profit. Commercial hunting, both legal and illegal, is the principal threat. Snowy egret, passenger pigeon, heath hen are USA examples. At $16,000 per pound and $40,000 to $100,000 per horn, it is little wonder that some rhino species are down to only a few thousand individuals, with only a slim hope of survival in the wild. The pet and decorative plant trade falls within this commercial hunting category, and includes a mix of legal and illegal activities. The annual trade is estimated to be at least $5 billion, with perhaps1/4 to 1/3 of it illegal.

Sport or recreational hunting causes no endangerment of species where it is well regulated, and may help to bring back a species from the edge of extinction. Many wildlife managers view sport hunting as the principal basis for protection of wildlife.

While over-hunting, particularly illegal poaching, remains a serious threat to certain species, for the future, it is less important than other factors mentioned next.

Habitat loss/degradation/fragmentation : Habit loss/degradation/fragmentation is an important cause of known extinction. As deforestation proceeds in tropical forests, this promises to become the cause of mass extinction caused by human activity.

Habitat damage, especially the conversion of forested land to agriculture, has a long human history. It began in China about 4,000 years ago, was largely completed in Europe by about 400 years ago, and swept across USA over the past 200 years or so. In the new world tropics, lowland, seasonal, deciduous forest began to disappear after 1500 with Spanish and Portuguese colonization of the New world. These were the forested regions most easily converted to agriculture, and with a more welcoming climate. The more forbidding, tropical humid forests came under attack mainly in 20th century, under the combined influences of population growth, inequitable land and income distribution, and development policies that targeted rain forests as the new frontier to colonize.

Tropical forests are so important because they harbor at least 50%, and perhaps more, of world's biodiversity. Direct observations, reinforced by satellite data, documents that these forests are declining. The original extent of tropical rain forests was 15 million km^2. Now there remains about 7.5-8 million km2, so half is gone. The current rate of loss is estimated at near 2% annually. While there is uncertainty regarding the rate of loss, and what it will be in future, the likelihood is that tropical forests will be reduced to 10-25% of their original extent by late. 21st century.

Habitat fragmentation is a further aspect of habitat loss that often goes unrecognized. The forest, meadow, or other habitat that remains generally is in small, isolated bits rather than in large, intact units. Each is a tiny island that can at best maintain a very small population. Environmental fluctuations, disease, and other chance factors make such small isolates highly vulnerable to extinction. Any species that requires a large home range, such as a grizzly bear, will not survive if the area is too small. Finally, we know that small land units are strongly affected by their surroundings in terms of climate, dispersing species, etc. As a consequence, the ecology of a small isolate may differ from that of a similar ecosystem on a large scale.

For the future, habitat loss, degradation, and fragmentation combined is the single most important factor in the projected extinction crisis.

Invasion of non-native species : Invation of non-native species is an important and often-overlooked cause of extinction. The African Great Lakes - Victoria, Malawi and Tanganyika are famous for their great diversity of endemic species, termed "species flocks", of cichlid fishes. In Lake Victoria, a single, exotic species, the Nile perch, has become established and may cause the extinction of most of the native species, by simply eating them all. It was a purposeful introduction for subsistence and sports fishing, and a great disaster.

Of all documented extinction since 1600, introduced species appear to have played a role in al least half. The clue is the disproportionate number of species lost from island : some 93% of 30 documented extinction of species and sub-species of amphibians and reptiles, 93% of 176 species and sub-species of land and freshwater birds, but only 27% of 114 species and sub-species of mammals. Why are island species so vulnerable, and why is this evidence of the role of non-indigenous species?

Islands are laboratories for evolution that effects the entire biological system. Effects are especially likely when two or more species are highly inter-dependent, or when the affected species is a "keystone" species, meaning that it has strong connections to many other species.

The seeds of the tree Calvaria major, now found exclusively on the island of Mouritius, must pass through the abrasive gut of a large animal in order to germinate. Their tough seed coats are protection against digestion, but also a kind of living coffin, for the seed can not germinate unless abraded. None of the animals currently on Mouritius have that ability. The dodo, hunted to extinction in the late 17th century probably was the key to recruitment in this species. Some seeds, abraded, roughened, and excreted by dodos, germinated and grew. Today, no seeds germinate, and only a few very old trees now survive. The blackfooted ferret was once very abundant in the western prairies. It preyed upon prairie dogs and used their burrows to nest in poisoning of prairie dogs has greatly reduced their abundance, and the blackfooted ferret is now the rarest mammal in North America.

Pollution : Pollution from chemical contamination certainly poses a further threat to species and ecosystems. While not commonly a cause of extinction, it likely can be for species whose range is extremely small, and threatened by contamination. Several species of desert pupfish, occurring in small isolated pools in the US southwest, are examples.

Climate change : A changing global climate threatens species and ecosystem. The distribution of species is largely determined by climate, as is the distribution of ecosystems and plant vegetation zones. Climate change may simply shift these distributions but, for a number of reasons, plants and animals may not be able to adjust. The pace of climate change almost certainly will be more rapid than most plants are able to migrate.

Presence of roads, cities, and other barriers associated with human presence may provide no opportunity for distributional shifts. Parks and nature reserves are fixed locations. For these reasons, some species and ecosystems are likely to be eliminated by climate change. Agricultural production likely will show regional variation in gains and losses, depending upon crop and climate.

As a consequence of these multiple forces, many scientists fear that by end of next century, perhaps 25% of existing species will be lost. Estimates of current and future extinction rates are based on well-documented relationships between the number of species in a region and habitat area, and on reasonable well-known rates of habitat loss. We must also employ some ratio to approximate the total number of species, from the number of described species. The relationship between species (S) and area (A) is described by the equation : S = CAz, where z is the slope of the log-linear relationship, and C is a constant which described the height of the line. Based on censuses of species on islands, the number of species found on an island increases log-linearly with island area. Conversely, as island is reduced, so is the number of species that will be found there. The slope (z) usually varies between 0.15 to 0.35. When combined with current rates of loss of tropical forest, these values of the slope translate into species extinction rates of roughly 0.5% annually. Extrapolated to the year 2020, roughly 20% of remaining species will disappear. Simply using the most conservative values of the slope, and assuming the true biodiversity to tropical forests is roughly 10 million species, the projected rate of loss of species is 27,000 per year, and three during this hour.

UNIT 8 ☐ Approaches Determining Conservation Priorities

Structure

8.1 Introduction

8.2 The regional approach

8.3 The national approach

8.1 Introduction

Some ecosystems within a nation have more species than others, so do some nations have more species than others (usually because they contain more ecological diversity). It seems worthwhile to identify which parts of the world contain the greatest diversity. This problem can be approached on at least three different levels : the region, the nation, and the site.

8.2 The regional approach

8.2.1 The regional approach : Critical areas in tropical forests and temperate areas

It is generally accepted that the greatest threat of species loss is in the tropical forests, which are thought to contain at least half the world's species on just 7 percent of the world's land surface (Wilson, 1988a). But within this richest of the world's biomes, a relatively small number of particularly rich areas harbor an inordinately large share of the earth's biodiversity, featuring exceptional concentrations of species with exceptional levels of endemism.

The committee on Research Priorities in Tropical Biology (NAS, 1980) identified 11 areas in the tropics that, because of their great biological diversity, high levels of endemism, and the rate with which their forests are being converted to other purposes, seem to demand special attention. These are :

- Coastal forests of Ecuador,
- The " Cocoa region" of Brazil,

- Eastern and southern Brazilian Amazon,
- Cameroon,
- Mountains of Tanzania,
- Madagascar,
- Sri Lanka
- Borneo,
- Sulawesi,
- New Caledonia, and
- Hawaii.

Myers (1988c) developed the approach to critical areas identifying 10 tropical forest "hotspots, " (Plus 2 in the developed world -Hawaii and Queensland) totaling about 3.5 percent of the primary remain tropical forest (and only 0,2 percent of the land surface of the planet) but containing at least 27 percent of the higher plant species found in the tropics, no less than 13.8 percent of the world's plants are found only in these hotspots.

The focus on tropical countries, however, can lead to insufficient attention being given to extremely important temperate areas. For example, of the 23,200 species of plants estimated to occur in Southern Africa (South Africa, Lesotho, Swaziland, Namibia and Botswana), 18,560 (i.e., 80 percent) are endemic to the region. This gives the area the highest species richness (calculated as species/area ratio) in the world, 1.7 times greater than that of Brazil. Of these, 2,373 have been reported as threatened,

8.2.2 The regional approach : diversity in the seas

While the tropical forests are thought to still contain millions of undescribed species, the world's oceans are also poorly known and regularly yield major new discoveries. A totally new phylum, Loricifera, was described only in 1986; a shark over 5 meters long (known as "the megamouth shark") has been discovered in the past decade a species of mussel living near hydrocarbon seeps in the Gulf of Mexico was found to be feeding on methane. Deep-sea communities have been found to be far richer than suspected, with seafloor sediments at depths of 1,500 to 2,500 meters off the coast of New Jersey found to contain 898 species in more than a hundred families and a dozen phyla (Grassle, 1989). Entirely new habitats - hydrothermal ocean vents have been discovered in the past decade to consist of at least 16 previously unknown families of invertebrates. At the higher taxonomic level of phylum, marine ecosystems are actually more diverse than either terrestrial or fresh water biomes, with more phyla and endemic phyla.

The oceans are a great new frontier whose productivity is just beginning to be harnessed by humans. Far greater efforts are required to ensure that the exploitation is based on a more complete knowledge of how marine ecosystems function, how marine biodiversity contributes to productivity, and what management activities are required to ensure that the characteristic diversity of the seas is maintained.

8.3 The National Approach : "Megadiversity Countries"

As developed by Mittermeier,1988, Mittermeier and Warmer, 1989, the megadiversity country concept recognizes that :

- Basic scientific information on biodiversity and endangered ecosystems should be our first step in assessing international conservation priorities and conservation programmes are to be developed with and by the governments of sovereign national.
- Biodiversity is by no means evenly distributed among the world's 168 countries; and that a very small number of countries, lying partly or entirely within the tropics, accounts for a very high percentage of the world's biodiversity (including marine, freshwater and terrestrial diversity), and that these countries require very special international conservation attention.

The megadiversity concept integrates biological information of many different kinds, but the two main criteria for inclusion in this category are total species numbers and levels of endemism both as the species level and at higher taxonomic categories (e.g., genus, family).

Although data are still being gathered on this topic, preliminary indications are that about a dozen countries belong to the megadiversity list, including Brazil, Colombia, Ecuador, Peru, Mexico, Zaire, Madagascar, Australia, China, India, Indonesia and Malaysia. These countries by themselves account for 60 to 70 percent (and perhaps even more) of all the world's biodiversity. Of these, Brazil, Colombia, Indonesia and Mexico are especially rich in species numbers (and often have high endemism as well) for most groups of organisms on which information is available. Madagascar and Australia, though usually not as high in total species numbers (but see Box 19 for reptile diversity in Australia), belong to the megadiversity list because of their very high degrees of endemism, both at the species level and also at higher taxonomic categories like the genus and family. Although the megadiversity countries (e.g., Brazil, China) are among the world's largest and would be expected to have high diversity simply because of their size, their diversity for exceeds that of other countries of similar size (e.g., Canada, U.S.A, Russia). Furthermore, several of megadiversity countries are quite small (e.g. Ecuador, Madagascar, Malaysia), with the diversity being due more to topography, climate and/or long isolation than to surface area. In any case, large, small or medium - sized, these countries have great strategic importance in conservation of biological diversity worldwide. They themselves have a great responsibility to the world to conserve their biological wealth, and the international community has a special responsibility to them to provide any assistance that might be required to achieve their conservation goals.

The biological resources of each and every country are of critical importance, at least to their own survival and well being (even not particularly important in the global picture), and therefore worthy of national and international attention for the reason alone. Rather, the megadiversity approach is aimed at focusing attention on these highly diverse, strategically critical megadiversity countries roughly in proportion to the biological wealth that they harbor and regardless of how difficult it might be to achieve conservation within them. Furthermore, it recognizes that if we do not pay sufficient attention to these megadiversity countries, we will loss a major percentage of the world's biodiversity regardless of how successful we are in the other less diverse countries.

UNIT 9 ❑ Biodiversity Distribution of the World

Structure

9.1 A profile of biodiversity distribution

9.2 Biodiversity profile of India

9.3 Biodiversity

9.1 A profile of biodiversity distribution

Globally, about 1.7 million organisms have been indentified and designated. About 6% of the identified species life in boreal or polar latitudes, 59% in the temperate zones, and the remaining 35% in the temperate zones, and the remaining 35% in the tropics (See Table below).

Table : The estimated number of species in three major climatic zones

Zones	Number of identified species (x 106)	Estimated total number of species	
		Assume 5 × 106	Assume 10x 106
Boreal	0.1	0.1	0.1
Temperate	1.0	1.2	1.3
Tropical	0.6	3.7	8.6
Total	1.7	5.0	10.0

Clearly, tropical and subtropical biotas are much more species rich than those of temperature higher-latitude regions. Invertebrates comprise the largest proportion of described species, with insects making up the bulk of that total, and beetles (Coleoptera) comprising the greater fraction of the insects.

Table : Estimated number of species in various classes of organisms

	Number of identified species	Estimated total number of species
Nonvascular plants	150.000	200.000
Vascular plants	250.000	280.000
Invertebrates	1,300.000	4,400.000b
Fishes	21.000	23.000
Amphibians	3123	3500
Reptiles	5115	6000
Birds	8715	9000
Mammals	4170	4300
Total	1,742.000	4,926.000

Furthermore, it is believed that there is a tremendous richness of undescribed insects in the tropics, possibly as many as another 30 million species, again mostly beetles.

These estimates of enormous numbers of underscribed species of tropical insects have been challenged as being unrealistically large (*e.g.*, Gaston, 1991). In some respects, however, the actual numbers of insect species are less important than the fact that so many of them are becoming extinct through loss of their tropical forest habitats.

Although it is often downplayed in conservation programmes that tend to focus on large, charismatic vertebrates or on particularly noteworthy plants, the species richness of insects and other invertelrates is ecologically important in its own right. Acording to Janzen (1987), these animals "are more than just decorations on the plants, rather they are the building blocks and glue for much of the habitat." These conclusions were based on a number of observations, including the following : (I) insects are the primary foods of most of the small, vertebrates carnivores of tropical forest; (2) insects are important predators of seeds and they thereby influence the plant species composition of the forest, and (3) insects are important pollinators, often in obligate, species specific relationship with particular plant species. These and other observations indicate that insects have a strong influence on the structure and functioning of tropical ecosystems.

These tropical forests are much more species rich than temperate forests, which typically have fewer than 12-15 tree species. The great smokes of the United States harbur some of the richest temperate forests in the world, and they typically contain 30-35 species (Leigh, 1982).

Note, however, that not all tropical forests are rich is species. In Sumatra, for example, mangrove forests only have about six species of tree, while some lowland stands dominated by ironwood (Ensider oxylon zwageri) are virtually monospecific, with as many as 96% of trees being this valuable species, prsent in all size and age categories (Whiten et al., 1987).

A few systematic studies have been made of the richness of avian species in plots of moist tropical forest. Ferborgh et al. (1990) found 245 resident and another 74 transient species in a a7-ha plot of Amazonian floodplain forest in peru. Thiollay (1992) recorded 239 species of birds in a primary Amazonian rainforest in Franch Guiana, Whitten et al. (1987) reported 151 species in a 15-ha plot of lowland forest in Sumatra. These species richness are substantially greater than what is found in typical, temperate forests in North America. For example, during a 15 year monitoring period, the number of bird species breeding in a 10-ha plot of hardwood forest at Hubbard Brook, New Hampshire, ranged from 17 to 28 (Holmes *et al.* 1986).

There have been few systematic studies of all biota of particular tropical ecosystems. In one case, a savannah like, dry tropical forest in Costa Rica was studied for several years (Janzen, 1987). It was estimated that a particular 108 - km2 reserve had about 700 plant species, 400 vertebrate species, and a remarkable 13 thousand species of insects, including 3140 species of moths and butterflies.

9.2 Biodiversity profile of India

Geography and Major Biomes

India is the seventh largest country in the world and Asia's second largest nation with an area of 3,287,263 square km. The Indian mainland stretches from 8 4' to 37 6' N latitude and from 68 7' to 97 25' E longitude (Figure 1). It has a land frontier of some 15,200 kms and a coastline of 7,516 km. India's northern frontiers are with Zizang (Tibet) in the Peoples Republic of China, Nepal and Bhutan. In the north-west, India borders on Pakistan; in the north-east, Bangladesh and China and Myanmar; and in the east, Myanmar The southern peninsula extends into the tropical waters of Indian Ocean with the Bay of Bengal lying to the south-east and the Arabian Sea to the south-west.

Physically the massive country is divided into four relatively well defined regions - the Himalayan mountains, the Gangetic river plains, the southern (Deccan) plateau, and the islands of Lakshadweep, Andaman and Nicobar. The Himalayas in the far north include some of the highest peaks in the world. The highest mountain in the Indian Himalayas is Khangchenjunga (8586 m), which is located in Sikkim on the border with Nepal. To the south of the main Himalayan mass lie the Lesser Himalaya, rising to 3,600-4,600 m, and represented by the Pir Panjal in Kashmir and Dhaula dhar in Himachal Pradesh. Further south, flanking the Indo-Gangetic Plain, are the Siwaliks, which rise to 900-1,500 m.

The northern plains of India stretch from Assam in the east to the Punjab in the west (a distance of 2,400 km), extending south to terminate in the saline swamplands of the Rann of Kachchh (Kutch), in the state of Gujarat. Some of the largest rivers in India including the Ganga (Ganges), Ghrghara, Brahmaputra, and the Yamuna flow across this region. The delta area of these rivers is located at the head of the Bay of Bengal, partly in the Indian state of west Bengal but mostly in Bangladesh. The plains are remarkably homogeneous topographically : for hundreds of kilometres the only perceptible relief is formed by floodplain bluffs, minor natural levees and hollows known as 'spill patterns', and the belts of ravines formed by gully erosion along some of the larger rivers. In this zone, variation in relief does not exceed 300 m (FAO/UNEP, 1981) but the uniform flatness conceals a great deal of pedological variety. The agriculturally productive alluvial silts and clays of the Ganga-Brahmaputra delta in north-eastern India, for example, contrast strongly with the comparatively sterile sands of the Thar Desert which is located at the western extremity of the Indian part of the plains in the state of Rajasthan.

The climate of India is dominated by the Asiatic monsoon, most importantly by rains from the southwest between June and October, and drier winds from the north between December and February. From March to May the climate is dry and hot.

Wetlands

India has a rich variety of wetland habitats. The total area of wetlands (excluding rivers) in India is 58,286,000ha, or 18.4% of the country, 70% of which comprises areas under paddy cultivation. A total of 1,193 wetlands, covering an area of about 3,904,543 ha, was recorded in a preliminary inventory coordinated by the Department of Science and Technology, of which 572 were natural (Scott, 1989). Two sites - Chilka Lake (Orissa) and Keoladeo National Park (Bharatpur) - have been designated under the Convention of Wetlands of International Importance (Ramsar Convention) as being especially significant waterfowl habitats. The country's wetlands are generally differentiated by region into eight categories (Scott, 1989) : the reservoirs of the Decan Plateau in the south, together with the lagoons and the other wetlands of the southern west coast; the vast saline expanses of Rajasthan, Gujarat and the gulf of Kachchh; freshwater lakes and reservoirs from Gujarat eastwards through Rajasthan (Kacoladeo Ghana National park) and Madhya Pradesh, the delta wetlands and lagoons of India's east coast (Chilka Lake); the freshwater marshes of the Gangetic Plain; the floodplain of the Brahmaputra; the marshes and swamps in the hills of north-east India and the Himalayan foothills; the lakes and rivers of the montane region of Kashmir and Ladakh; and the mangroves and other wetlands of the island arcs of the Andamans and Nicobars.

Forests

India possesses a distinct identity, not only because of its geography, history and culture but also because of the great diversity of its natural ecosystems. The panorama of Indian forests ranges from evergreen tropical rain forests in the Andaman and Nicobar Islands, the Western Ghats, and the north-eastern states, to dry alpine scrub high in the Himalaya to the north. Between the two extremes, the country has semi-evergreen rain forests, deciduous monsoon forests, thorn forests, subtropical pine forests in the lower montane zone and temperate montane forests (Lal, 1989).

One of the most important tropical forests' classifications was developed for Greater India (Champion, 1936) and later republished for present-day India (Champion and Seth, 1968). This approach has proved to have wide appliation outside India. In it, 16 major forests types are recognised, subdivided into 221 minor types. Structure, physiognomy and floristics are all used as characters to define the types.

The main areas of tropical forest are found in the Andaman and Nicobar Islands; the Western Ghats, which fringe the Arabian Sea coastline of peninsular India; and the greater Assam region in the north east. Small remnants of rain forest are found in Orissa state. Semi-evergreen rain forest is more extensive than the evergreen formation partly because evergreen forests tend to degrade to semi-evergreen with human interference. There are substantial differences in both the flora and fauna between the three major rain forest regions (IUCN, 1986; Rodges and Panwar, 1988).

The Western Ghats Monsoon forests occur both on the western (coastal) margins of the ghats and on the eastern side where there is less rainfall. Figure 4 shows the distribution of forest in Kerala State, which contains part of the Western Ghats range. These forests contain several tree species of great commercial significance (*e.g.* Indian rosewood *Dalbergia latifolia*, Malabar Kino *Pterocarpus marsupium*, teak and *Terminalia crenulata*), but they have now been cleared from many areas. In the rain forests there is an enormous number of tree species. At least 60 percent of the trees of the upper canopy are of species which individually contribute not more than one percent of the total number. Clumps of bamboo occur along streams or in poorly drained hollows throuout the evergreen and semi-evergreen forests of south-west India, probably in areas once cleared for shifting agriculture.

The tropical vegetation of north-east India (which includes the states of Assam, Nagaland, Manipur, Mizoram, Tripura and Meghalaya as well as the plain regions of Arunachal Pradesh) typically occurs at elevations up to 900 m. It embraces evergreen and semi-evergreen rain forests which are found in the Assam Valley, the foothills of the eastern Himalayas and the lower parts of the Naga Hills, Meghalaya, Mizoram, and Manipur where the rain fall exceeds 2300 mm per annum. In the Assam Valley the giant *Dipterocarpus macrocarpus* and *Shorea assamica* occur singly, occasionally attaining a girth of up to 7 m and a height of up to 50 m. The monsoon forests are mainly moist sal *Shorea robusta* forests, which occur widely in this region (IUCN, 1991).

The Andamans and Nicobar islands have tropical evergreen rain forests and tropical semi-evergreen rainforests as well as tropical monsoon/moist monsoon forests (IUCN, 1986). The tropical evergreen rain forest is only slightly less grand in stature and rich in species than on the mainland. The dominant species is *Dipterocarpus grandiflorus* in hilly areas, while *Dipterocarpus kerrii* is dominant on some islands in the southern parts of the archipelago. The monsoon forests of the Andamans are dominated by *Pterocarpus dalbergioides* and *Terminalia* spp.

Marine Environment

The nearshore coastal waters of India are extremely rich fishing grounds. The total commercial marine catch for India has stabilised over the last ten years at between 1.4 and 1.6 million tonnes, with fishes from the clupeoid group (e.g. sardines *Sardinella* sp., Indian shad *Hilsa* sp. And whitebait *Stolephorus* sp.) accounting for approximately 30% of all landings. In 1981 it was estimated that there were approximately 180,000 non-mechanised boats (about 90% of India's fishing fleet) carrying out small scale, subsistence fishing activities in these waters. At the same time there were about 20,000 mechanishtra, Kerala, Gujarat, Tamil Nadu and Karnataka.

Coral reefs occur along only a few sections of the mainland, principally the Gulf of Kutch, off the southern mainland coast, and around a number of islands opposite Sri Lanka. This general absence is due largely to the prsence of major river systems and the sedimentary regime on the continental shelf. Elsewhere, corals are also found in Andaman, Nicobar (**Figure 5**), and Lakshadweep island groups although their diversity is reported to be lower than in south-east India (UNEP/IUCN, 1988).

Indian coral reefs have a wide range of resources which are of commercial value, Exploitation of corals, coral debris and coral sands is widespread on the Gulf of Mannar and Gulf of Kutch reefs, while ornamental shells, chanks and pearl oysters are the basis of an important reef industry in the south of India. Sea fans and seawees are exported for decorative purposes, and there is a spiny lobster fishing industry along the south-east coast, notably at Tuticorin, Madras and Mandapam Commercial exploitation of aquarium fishes from Indian coral reefs has gained importance only recently and as yet no organized effort has been made to exploit these resources. Reef fisheries are generally at the subsistence level and yields are unrecorded.

Other notable marine areas are seagrass beds, which although not directly exploited are valuable as habitats for commercially harvested species, particularly prawns, and mangrove stands. In the Gulf of Mannar the green tiger prawn *Penaeus semisulcatus* is extensively harvested for the export market. Seagrass beds are also important feeding areas for the dugong *Dugong dugon,* plus several species of marine turtle.

Five species of marine turtle occur in Indian waters; Green turtle *Chelonia mydas,* Loggerhead *Caretta caretta,* Olive Ridley *Lepidochelys olivacea,* Hawksbill *Eretmochelys imbricata* and Leatherback *Dermochelys coriacea.* Most of the marine turtle populations found in the Indian region are in decline. The principal reason for the decrease in numbers is deliberate human predation. Turtles are netted and speared along the entire Indian coast. In south-east India the annual catch is estimated at 4,000-5,000 animals, with *C. mydas* accounting for about 70% of the harvest. *C. caretta* and *L. olivacea* are the most widely consumed species (Salm, 1981). *E. imbricata* is occasionally eaten but it has caused deaths and so is usually caught for its shell alone. *D. coriacea* is boiled for its oil which is used for caulking boarts and as protection from marine borers. Incidental netting is widespread. In the Gulf of Mannar turtles are still reasonably common near seagrass beds wehre shrips trawlers operate, but off the coast of Bengal the growing number of mechanized fishing boats has had the effect of increasing incidental catch rates (Kar and Bhaskar, 1981).

9.3 Biodiversity

Species diversity

India contains a great wealth of biological diversity in its forests, its wetlands and in its marine areas. This richness is shown in absolute numbers of species and the proportion they represent of the world total.

Table. Comparison between the Number of Species in India and the World.

Group	Number of species in India (SI)	Number of species in the world (SW)	SI / SW (%)
Mammals	350(1)	4,629(7)	7.6
Birds	1224(2)	9,702(8)	12.6
Reptiles	408(3)	6,550(9)	6.2
Amphibians	197(4)	4,522(10)	4.4
Fishes	2546(5)	21,730(11)	11.7
Flowering Plants	15,000(6)	250,000(12)	6.0

India has a great many scientific institutes and university departments interested in various aspects of biodiversity. A large number of scientists and technicians have been engaged in inventory, research, and monitoring. The general state of knowledge about the distribution and richness of the country's biological resources is therefore fairly good.

Inventories of birds, mammals, trees, fish and reptiles are moderately complete Knowledge of special interest groups such as primates, pheasants, endemic birds, orchids, and so on, is steadily improving through collaboration of domestic scientists with those from overseas.

Endemic species

India has many endemic plant and vertebrate species. Among plants, species endemism is estimated at 33% with 140 endemic genera but no endemic families (Botanical Survey of India, 1983). Areas rich in endemism are north-east India, the Western Ghats and the north-western and eastern Himalayas. A small pocket of local endemism also occurs in the Eastern Ghats. The Gangetic plains are generally poor in endemics, while the Andaman and Nicobar Islands contribute at least 220 species to the endemic flora of India (Botanical Survey of India, 1983).

WCMC's Threatened Plants Unit (TPU) is in the preliminary stages of cataloguing the world's centres of plant diversity; approximately 150 botanical sites worldwide are so far recognized as important for conservation action, but others are constantly being identified (IUCN, 1987). Five locations have so far been issued for India : the Agastyamalai Hills, Silent Valley and New Amarambalam Reserve and Periyar National Park (all in the Western Ghats), and the Eastern and Western Himalaya. Endemism among mammals and birds is relatively low. Only 44 species of Indian mammal have a range that is confined entirely to within Indian territorial limits. Four endemic species of conservation significance occur in the Western Ghats. They are the Lion-tailed macaque *Macaca silenus,* Nilgiri leaf monkey *Trachypithecus johni* (locally better known as Nilgiri langur *Presbytis johnii*), Brown palm civet *Paradoxurus jerdoni* and Nilgiri tahr *Hemitragus hylocrius.*

Only 55 bird species are endemic to India, with distributions concentrated in areas of high rainfall. These areas, mapped by BirdLife International (formerly the International Council for Bird Preservation) are shown in Figure 7. They are located mainly in eastern India along the mountain chains where the monsoon shadow occurs, south-west India (the Western Ghats), and the Nicobar and Andaman Islands (ICBP, 1992). In contrast, endemism in the Indian reptilian and amphibian fauna is high. There are around 187 endemic reptiles, and 110 endemic amphibian species. Eight amphibian genera are not found outside India. They include, among the caecilians, *Indotyphlus, Gegeneophis* and the frogs *Ranixalus, Nannobatrachus* and *Nyctibatrachus*. Perhaps most notable among the endemic amphibian genera is the monotypic *Melanobatrachus* which has a single species known only from a few specimens collected in the Anaimalai Hills in the 1870s (Groombridge, 1983). It is possibly most closely related to two relict general found in the mountains of eastern Tanzania.

Threatened species

India contains 172 species of animal considered globally threatened by IUCN, or 2.9% of the world's total number of threatened species (Groombridge, 1993). These include 53 species of mammal, 69 birds, 23 reptiles and 3 amphibians. India contains globally important populations of some of Asia's rarest animals, such as the Bengal Fox, Asiatic Cheetah, Marbled Cat, Asiatic Lion, Indian Elephant, Asiatic Wild Ass, Indian Rhinoceros, Markhor, Gaur, Wild Asiatic Water Buffalo etc.. The number of species in various taxa that are listed under the different categories of endangerment is shown below in the **Table.**

Table : Globally Threatened Animals Occuring in India by Status Category.

Group		1994 IUCN	Red List	Threat Category	
	Endangered	Vulnerable	Rare	Indeterminate	Insufficiently Known
Mammals	13		20	5	13
Birds	6	20	25	13	5

Group		1994 IUCN	Red List	Threat Category	
	Endangered	Vulnerable	Rare	Indeterminate	Insufficiently Known
Reptiles	6	6	4	5	2
Amphibians	0	0	0	3	0
Fishes	0	0	2	0	0
Invertebrates	1	3	12	2	4
TOTAL	26	49	45	2	24

Source : Groombridge, B. (ed). 1993. The *1994 IUCN Red List of Threatened Animals.* IUCN, Gland, Switzerland and Cambridge, UK, lvi+286 pp.

A workshop held in 1982 indicated that as many as 3,000-4,000 higher plants may be under a degree of threat in India. Since then, the Project on Study, Survey and Conservation of Endangered species of Flora (POSSCEP) has partially documented these plants, and published its findings in Red Data Books (Nayar and Sastry, 1987).

UNIT 10 ❑ Theories on Biodiversity

The following are the different theories relating to biodiversity.

1. The Time hypothesis : In 1878, the English naturalist Alfred Russel Wallace suggested that diversity in the tropics was greater than in temperate regions because tropical conditions appeared on the earth's surface earlier than more polar environments. Furthermore, temperate regions have been subjected to more frequent and widespresd disturbance - for example, glaciation - than tropical regions during the history of the earth. Thus, tropical regions have enjoyed longer periods of stability and, thus, have had more time for species differentiation. This idea is now sometimes referred to as the time hypothesis of species diversity.

A number of types of evidence may be used to examine the time hypothesis.

Evidence from the fossil record that diversity has increased over time would lend support to the time hypothesis. The fossil record is so fragmentary that this test can be applied to only a few taxa and is restricted to certain types of habitats, particularly marine habitats.

2. Species diversity increases with primary production : Primary production sets a limit on the amount of energy available for use by species within a community. Thus, we might expect that species richness would be limited by the productivity of the environment. Some authors suggested that species richness should be greatest in relatively stable environments having high rates of productivity. This idea, which was first proposed by Whittaker and Niering and given theoretical grounding by Tilman, is called the productivity - stability hypothesis of species diversity. On a regional scale - that is, over areas of about 106 km² - species diversity has been found to be positively related to productivity in some cases. However, it is unclear how strong the relationship between productivity and species richness is, or what the possible mechanisms for such a relationship might be. Tilman and Pacala suggest that diversity does not increase monotonically with productivity for any group of species, but that species richness varies depending on what environmental factor is used as a measure of productivity and which species are being considered. Currie found that bird, mammal, amphibian, and reptile species richness increased with increasing potential evapotranspiration. For amphibians and reptiles, the increase was monotonic; for birds and mammals, there was a slight but insignificant decrease in richness at the higher PET levels.

Rosenzweig and Abramsky have recently evaluated other ideas regarding the relationship between productivity and species richness. One possibility is that productivity is simply correlated with species richness, rather than a determinant of it. That is to say, some other factor, such as disturbance, the spatial distribution of habitats, or some other as yet unidentified variable that is correlated with productivity may be at play. For example, some have suggested that predator - prey ratios increase as productivity increases, and thus, at high productivity levels, predators consume a disproportionate share of the available production, thereby causing a reduction in community diversity.

3. Intertaxon competition hypothesis : Rosenzweig and Abramsky have suggested that two hypotheses are most worthy of further consideration. The first is what they call the intertaxon competition hypothesis. This idea holds that the peaks of species diversity for different multispecies taxa should occur in areas having different productivity levels. For example, they point out that among small mammals in the south - western deserts of the low productivity west of the El paso River, whereas carnivore species richness is highest in East Texas in areas of much higher productivity. Rosenzweig and Abramsky suggest that, as a whole, a taxon will compete better at a certain productivity level than at others. Consequently, where that productivity level exists, that taxon will have an advantage over another taxon whose richness peaks at another productivity level, thereby reducing overall species richness through intertaxon competition. Rosenzweig and Abramsky hasten to point out that this idea is virtually untested.

4. Habitat heterogeneity : Another hypothesis worthy of consideration is that of Tilman and others, who have suggested that habitat heterogeneity increases with productivity to a certain point, after which it decreases.

5. Lottery hypothesis : Colonization by lottery, which produces random variation in time, reduces competitive exclusion to chance extinction and may contribute to the coexistence of large numbers of fish species in tropical reef communities. But the lottery model cannot explain the high diversity of larval fish in the plankton from which coral residents come. Nor can it explain the difference in fish diversity between tropical and temperate oceans.

6. Pest pressure hypothesis : Naturalists have thought that both selective and nonselective herbivory may influence the diversity of plant species. In particular, several authors have suggested that herbivory could promote the high diversity of tropical forests. It is argued that herbivores feed upon the buds, seeds, and seedlings of abundant species so efficiently that their densities are reduced. This allows other, less common species to grow. The key to this idea is that abundance *per se*, rather than the intrinsic quality of individuals as food items, makes a species vulnerable to consumers. Consumers locate abundant species easily, and their own populations grow to high levels. This idea became known as the pest pressure hypothesis.

7. Intermediate disturbance hypothesis : A number of mechanisms have been proposed to explain the effects of disturbance on species diversity. Consideration of tropical rain forests and coral reefs led scientists to relate high diversity to intermediate levels of disturbance, an idea referred to as the intermediate disturbance hypothesis. Disturbances caused by physical conditions, predators, or other factors open space for colonization and initiate a cycle of succession by species adapted to colonize disturbed sites. With a moderate level of disturbance, the community becomes a mosaic of patches of habitat at different stages of regeneration; together these patches contain the full variety of species characteristic of the successional sere. For this hypothesis to account satisfactorily for differences in diversity between regions, especially on the magnitude of the latitudinal difference in tree species diversity, there must be comparable differences in levels of disturbance. Rates of turnover of individual forest trees do not differ systematically between temperate and tropical areas. Nor is it likely that major disturbances such as storms and fires are more frequent in the Tropics. Thus, while distirbance may promote diversity, it seems unlikely to account for much of the observed variation in diversity among forests or, indeed, other types of communities.

UNIT 11 ❑ Introductory Note on Conservation

Structure

11.1 Wild life

11.2 Wild life wealth of India

11.3 Causes of wildlife depletion

11.4 Wild life : present status

11.1 Wild life

Wildlife commonly refers to all wild undomesticated animals in their natural habitats. Philosophically, it should include all the biotic elements that evolved and flourished as a consequence of evolution. From ecological point of view, it includes every form of life-flora and fauna in their natural habitats.

Wildlife embraces all living creatures and implies their conservation (E. P. Gee, 1964).

According to wildlife society, wildlife includes all wild vertebrates and larger invertebrates important from aesthetic, sporting, utilitarian and nuisance standpoint.

According to Wildlife (Protection) Act, it includes any animal, bees, butterflies, crustacean, fish and moths and aquatic and land vegetation which forms part of any habitat.

The term 'wildlife' is appropriate while dealing with the management control and conservation of wild animal population as a whole as distinct from the purely game animals.

11.2 Wildlife wealth of India

India is very rich in biodiversity. India is one of the twelve megadiversity country and has three hot spots region (Western Ghats, Khasi- Manipur and Eastern Himalayas) out of twenty five.

It is estimated that 18% of the Indian plants are endemic to the country and found nowhere else in the world. Among amphibians found in India, 62% are unique to this country. Among lizards, of the 153 species recorded, 50% are endemic. High endemism has also been recorded for various groups of insects, marine worms, centipedes, mayflies and freshwater sponges.

	India's world ranking	Number of species in India
Mammals	8th	350
Birds	8th	1200
Reptiles	5th	453
Amphibians	15th	182
Angiosperms	15th- 20th	14500

But unfortunately there are constant depletion of wildlife in India.

11.3 Causes of wildlife depletion

1. Due to natural calamities like floods, droughts, fire, epidemics, super cyclone and absence of cover or shelter to wild animals.

2. Sometimes distribution range and degree of specialization of their own leads toward extinction.

3. Unlimited and over exploitation of natural resources for our best possible life

4. Tremendous explosion of human population and as a result it demands development and further need for more food and urbanisation.

5. Encroachment of forst for agricultural extension, industry and mining operation.

6. Reckless deforestation for urbanisation, cultivation, road construction, railway routes, dam and hydroelectric projects resulting in reduction of free movement area and reduction in reproductive potentiality of most wild animals.

7. Hunting,poaching and trading of wild animals for food, recreation, skin, tusk, fur, horn, pharmaceuticals, perfume industries etc. is one of the major cause of loss of wildlife.

8. Pollution like noise and water adversely affect animal life.

9. Last but not the least is the lack of enforcement of existing laws.

11.4 Wildlife : present status

Of all vertebrate species world-wide, 6.69% are considered threatened and, of all invertebrate species, only 0.16% are considered threatened.

Estimated number of described species (2002)

Taxonomic Group	Number of species		% in India
	World	India	
Protista Protozoa	31250	2577	8.24
Total (Protista)	31250	2577	8.24
ANIMALIA			
Mesozoa	71	10	14.08
Porifera	4562	48	10.65
Cnidaria	991	842	8.49
Ctenophora	100	12	12.00
Platyhelminthes	17500	1622	9.27
Nemertinea	600	-	-
Rotifera	2500	330	13.20
Gastrotricha	3000	100	3.33
Kinorhyncha	100	10	10.00
Nematoda	30000	2850	9.50
Nematomorpha	250	-	-
Acanthocephala	800	229	28.62
Sipuncula	145	35	24.14
Mollusca	66535	5070	7.62
Echiura	127	43	33.86
Annelida	12700	840	6.61
Onychophora	100	1	1.00
Arthropoda	987949	68389	6.90
Crustacea	35534	2934	8.26
Insecta	867391	59353	6.83
Arachnida	73440	5818	7.90
Pycnogonida	600	16	2.67

Pauropoda	360	-	-
Chilopoda	3000	100	3.33
Diplopoda	7500	162	2.16
Symphyla	120	4	3.33
Merostomata	4	2	50.00
Phoronida	11	3	27.27
Bryozoa (Ectoprocta)	4000	200	5.00
Entroprocta	60	10	16.66
Brachiopoda	300	3	1.00
Pogonophora	80	-	-
Priapulida	8	-	-
Pentastomida	70	-	-
Chaetognatha	111	30	27.02
Tardigrada	514	30	5.83
Echinodermata	6223	765	12.29
Hemichordata	120	12	10.00
Chordata	48451	4952	10.22
Protochordata (cephalochordata + Urochordata)	2106	119	5.65
Pisces	21723	2546	11.72
Amphibia	5150	209	4.06
Reptilia	5817	456	7.84
Aves	9026	1232	13.66
Mammalia	4629	390	8.42
Total (Animalia)	1196903	86874	7.25
Grand total (Protista + Animalia)	1228153	89451	7.28

Estimated number/percentage of endemic species in India (2004)

Taxon	Number of species		Percentage
	Total	Endemic	(%)
Protozoa :			
Free living	1247	90	7.21
Parasitic	1330	550	41.33
Mesozoa	10	10	100.00
Porifera :			
Freshwater	31	13	41.93
Cnidaria	842	10	-
Platyhelminthes	1622	1160	71.88
Rotifera	330	23	7.00
Gastrotricha	100	64	64.00
Kinorhyncha	10	7	70.00
Nematoda	2850	400	-
Acanthocephala	229	203	88.64
Mollusca :			
Terrestrial	1487	498	33.50
Freshwater	183	77	41.80
Echiura Annelida	43	12	28.00
Oligochaeta	473	368	77.80
Hirudinea	59	25	'2.37
Arthropoda :			
Crustacea	2934	501	17.70
Insecta	59353	20717	34.90
Arachnida	5818	2623	45.08
Phoronida	11	1	1.00
Bryozoa	4000	12	-
Entoprocta	10	1	1.00
Chaetognatha	111	3	2.70

Chordata :			
Pisces	2546	223	8.75
Amphibia	209	128	61.24
Reptilia	456	214	47.00
Aves	1232	176	14028
Mammalia	390	36	9.23

Floral wealth of India and world number of species in different groups of plants in India and the world

Groups	Number of species			% of
	India		World	World flora
Angiosperms	17500	(5725)	250000	7.0
Gymnosperms	48	(10)	650	7.4
Pterydophytes	1200	(193)	10000	12.0
Bryophytes	2850	(938)	14500	19.7
Lichens	2021	(466)	13500	15.0
Fungi	14500	(3500)	70000	20.7
Algae	6500	(1924)	40000	16.25
Virus/ Bacteria	850		8050	10.6
Total	45469	(12756)	406700	11.18

UNIT 12 ❑ Biomes & Wild Life : Characterisation, Faunal make up & Adaptation

Structure

12.0 Boimes

12.1 Terrestrial biomes

12.2 Tropical rainforests

12.3 Desert biome

12.4 Marine enviornments

12.0 Biomes

Within these Bio-geographical realms regional climate interacts with regional biota and substrate to produce large easily recognizable community units called **Biomes**-characterized by the kinds of animals and plants present. The definition of biome not only includes the climax community of a region but also the several intermediate stages as well dominated by other life forms. Ecologists have identified the following biomes.

12.1 Terrestrial biomes :

Temperate climates are characterized by average annual temperatures in the range of 5°-50°C at low elevations. Such climates are distributed between approximately 30°N and 45°N in North America and between 40°N and 60°N in Europe, which is warmed by the Gulf Stream current. Frost is an important factor throughout the temperate zone. Seven terrestrial biomes of the temperate zone are listed below -

Deciduous Forest Biome : found in North America principally in the eastern part of the United States and Southern Canada, but also occurs widely in Europe and Eastern Asia. It is poorly developed in the Southern Hemisphere (New Zealand and Southern Chile) because of the milder winter temperatures at moderate latitudes. The vegetation is dominated by deciduous trees, predominantly oak, maple, beech, birch and hickory, often with a subcanopy layer of small trees and shrubs. Herbaceous plants complete their growth and flower early in spring, before the trees have fully leaved out.

Temperate Needle-leaved Biome : dominated by pines and exists under conditions of water and nutrient stress, often on sandy soils. The most important of these formations in North America are the pine forests of the coastal plains of the Atlantic and Gulf States, the jack pine forests of the northern parts of the Great Lakes states and central Canada, and the montane pine forests of the American West. Because soils tend to be dry, fires are frequent, and most species are able to resist fire damage.

Temperate Rain Forest Biome : occurs near the Pacific coast in the northwestern United States and British Colombia, and also in southern Chile, New Zealand and Tasmania. Mild winters, heavy winter rains and summer fog create conditions that support extremely tall evergreen forests. Trees are typically 60-70 meters high and may grow to over 100 meters. In contrast to rain forests in Tropics, the species diversity of temperate rain forests typically is very low.

Temperate Grassland Biome : develops where rainfall is between 30 and 85 cm per year, depending on the average temperature. Summers are hot and wet; winters are cold. North American grassland biomes are often called Prairies. Extensive grassland is also found in central Asia, where they are called Steppes. Because annual precipitation is low, organic detritus does not decompose rapidly, and the soils are rich in organic matter. The vegetations are dominated by grasses, which grow to over 2 meters in the moisture parts of the grassland biome and less than 0.2 meters in more arid regions. There are also nongrass herbaceous species, which are called forbs. Fire has a dominant influence in the grassland, particularly where the habitat dries out during the late summer. Most grassland species have fire-resistant underground stems or rhizomes or have fire-resistant seeds.

Temperate Shrub-land Biome : here precipitation ranges between 25 and 50 cm per year, and the winters are cold and the summers are hot. The shrub-land biome covers most of the Great Basin of the western United States. In these shrublands, potential evapotranspiration exceeds precipitation during most of the year, and so soils are dry and little water percolates through them to form streams and rivers. Fire occurs infrequently because the habitat produces little fuel.

Mediterranean Woodland Biome : distributed at 30°-40°latitude north and south of the Equator - somehow higher in Europe-on the western sides of continental landmass. Representatives of this biome include southern Europe and southern California in the Northern Hemisphere, and central Chile, the Cape region of South Africa, and southwestern Australia in the Southern Hemisphere. Mediterranean climates are characterized by mild temperature, winter rain and summer drought which support thick, evergreen, shrubby vegetation 1-3 meters in height, with deep roots and drought-resistant foliage.

Subtropical Desert Biome : develops at latitude of 20°-30° north and south of the Equator in areas with very sparse rainfall (less than 25 cm per year) and generally long growing seasons. Because of low rainfall, the soils of subtropical deserts are shallow, virtually devoid of organic matter and neutral in pH. Wetter sites support a profusion of succulent cacti, shrubs and small trees. Most subtropical deserts receive summer rainfall, during which many herbaceous plants sprout from dormant seeds and quickly grow and reproduce before the soils dry out again. Species diversity is much higher than it is in temperate lands.

Boreal and Polar Biomes : Three biomes are characteristic of the high latitudes of the Northern Hemisphere and of areas of high elevation in temperate and tropical regions.

Boreal Forest Biome or Taiga : stretches in a broad belt centered at about 50°N in North America and about 60°N in Europe and Asia. The average annual temperature is below 5°C and winters are severe (temperature may reach -60°C). Precipitation is in the range of 40-100 cm, and because evaporation is low, soils are moist throughout most of the growing season. The vegetation consists of vast, dense stands of evergreen needle-leaved trees, mostly spruce and fir, which grow to be 10-20 meters high. Because of the low temperature the leaf litter decomposes very slowly and accumulates at the soil surface. Species diversity is very low.

Tundra Biome : lies north of the boreal forest in the polar climate zone. It is treeless expanse underlain by permanently frozen soil or permafrost. The soils thaw to a depth of 0.5-1 meter during the brief summer growing season. Soils tend to be acid because of their high organic matter content, and they are very low in nutrients. Most plants are dwarfs, prostrate, woody shrubs.

Alpine Tundra Biome : these areas occur above the treeline, most broadly in Rocky Mountains in North America and especially in the Tibetan Plateau of central Asia. Alpine tundra generally have warmer and longer growing seasons, higher precipitation, less severe winters, greater productivity, better-drained soils and higher species diversity than the arctic tundra.

Equatorial and Tropical Biomes : In the regions of the world within 20°north and south of the equator, temperature vary more throughout the day than average monthly temperature s vary through the year. Average temperatures at sea level generally exceed 20°C. Environments of tropical latitudes are distinguished by the seasonal course of rainfall, which creates a continuous gradient of vegetation from wet, seasonal rain forests, to seasonal forests, to scrub, savanna and desert. Frost is not a factor in tropical biomes. Three biomes are typically distinguished within these equatorial and tropical climate zones.

Tropical Rain Forest Biome : develops in climates that are always warm and that receive at least 200 cm of precipitation throughout the year, with not less than 10 cm during any one month. These conditions exists in three important regions within the Tropics: the Amazon and Orinoco Basins of South America, with additional areas in Central America and along the Atlantic coast of Brazil, constitute the American rain forests; the area from southernmost West Africa and extending eastward to the Congo River basin constitute the African rain forests; and the Indo-Malayan rain forests cover parts of Southeast Asia, the islands between Asia and Australia and the Queensland coast of Australia.

Rain forest soils are typically old and deeply weathered. Because they are relatively devoid of humus and clay, they take on the reddish colour of aluminium and iron oxides and have poor ability to retain nutrients. In spite of the low nutrient status of the soils, rain forest vegetation is dominated by a continuous canopy of tall evergreen trees rising to 30-40 meters, with occasional emergent trees rising above the canopy to heights of 55 meters. The productivity of the rain forest biome is greater than that of any other terrestrial biome. Species richness is extremely high.

Tropical Seasonal Forest Biome : develops within the Tropics beyond 10° north and south of the equator. These climates often exhibit a pronounced dry season, corresponding to winter at higher latitudes. Seasonal forests in the Tropics have a preponderance of deciduous trees that shed their leaves during the season of water stress.

Tropical Savanna Biome : may be defined as grassland with scattered trees and it typifies large areas of the dry Tropics, especially in Africa. The tropical savanna biome has an average rainfall of 90-150 cm per year, but the driest three or four months receive less than 5 cm each. Fire and grazing play an important role in maintaining the character of the biome, particularly in wetter regions, as grasses can persist better than other forms of vegetation under these influences.

Note : The biome concept was developed for terrestrial ecosystems, and biomes are principally distinguished by the growth form of their dominant vegetation. As a consequence, "aquatic biomes" do not exist in the sense in which the term is applied to terrestrial ecosystems. Indeed, employing a vegetation concept would be impossible in aquatic systems because the primary producers in many aquatic systems are single-celled algae, which do not form "vegetation" with a characteristic structure. As a result, classifications of aquatic systems have been based primarily on physical characteristics : salinity, water movement, depth and so on. The major kinds of aquatic environments are streams, lakes, estuaries and oceans.

12.2 Tropical rainforests

1. Characteristics :

(I) **Location** : Located in a band around the Equator, between the Tropic of Cancer (23.5° N Latitude) and the Tropic of Capricorn (23.5° S Latitude) which forms a 4800 km wide band called 'Tropics'. Tropical rain forests are found in South America (the Amazon and Orinoco basins), West Africa (Congo, Niger & Zambezi basins), Australia, South-East Asia and India (Assam, Meghalaya, and Western Ghats).

(II) **Physical Enviornment** :

a. Very dense, warm, wet forest.

b. Temperature is high, but even and minimal seasonal changesare recorded (in summer : 13°C to 43°C and in winter : 10°C to 32°C).

c. Rainfall abundant (250 - 400 cm).

d. Temperature and relative humidity are comparatively high and remains constant throughout the day.

e. Due to high temperature evaporation is fast.

f. Days and nights are of uniform in length.

g. Soil which is exceedingly thick is red latosols. Leaching of minerals very fast-makes it unfit for agricultural practices.

h. Speedy nutrient cycling makes the soil very fertile.

i. Community is most diverse- heaven for both plants and animals.

j. **Nutrient cycling** : Tropical rain forests are found on soils which are nutrient poor. However, high productivity does not require soils to contain large nutrient reserves. What seems to happen in undisturbed tropical rain forests is that any organic matter that falls on the ground is rapidly decomposed. The nutrients thus released into the soil are then rapidly taken up by the surface roots of trees and other plants or occasionally leached from the soil.

Tropical trees produce a large number of biomass which is concentrated near the surface. These roots seem to be very effective in absorbing nutrients. Another feature of tropical trees which favour nutrient retention is that, their leaves are often long lived, tough and resistant to insect attacks.

(III) **Zonations** : Based on living environment rain forests may be divided into I :

a. Emergents : Giant trees (200 ft) much higher than average canopy height. Emergent dwelling animals are birds and insects.

b. Canopy (80-100 ft.) : Uppermost part of trees, leafy environment and full of insects, reptiles, birds, mammals.

c. Understory : A dark cool environment under the leaves over the ground.

d. Forest floor : Teeming with animal life, specially insects and large mammals.

2. Faunal make-up :

a. Rich in density as well as in varieties.

b. Animal communities are stratified vertically.

c. Mostly arboreal forms (Sloths, lemurs, *Dendrologous* sp, bats etc.), some ground dwellers (*Panthera tigris, Elephas maximus, Bos gaurus; Axis axis* - from peninsular India) and few amphibians.

d. Majority of the animals are nocturnal in habit.

e. Symbiosis between animals and epiphytes very common.

f. Invertebrate density and abundance very high- worms, snails, centipedes, millipedes, isopods, spiders, scorpions, leeches and insects (heteroptera, orthoptera, mantids, Phasmids, butterflies, bees, ants, termites.)

g. Vertebrates mostly arboreal :

Amphibians : *Hyla, Rachophora.*

Reptiles : Iguanas, Geckos, Chameleons, snakes.

Birds : Parakeets, Hornbills (frugivorous), humming birds (necter feeding), woodpeckers etc. are common.

Mammals : Insectivores, leopards, jungle cat, flying squirrels, monkey, Sloths, deers etc.

3. Adaptations :

Each species has evolved with its own sets of unique adaptations so as to survive. Every animal has the ability to protect itself from being the next meal. In rainforest there are twigs that walk, leaves that leap bark that flies, and masses of thorns that explode into fragments when touched. Insects frogs, lizards, snakes, birds, cats find refuge by blending into pattern and textures of the rain forest.

Protective mimicry/colorations :

Organisms mimic either some other organism or object in form colour or behaviour to protect themselves from predators. This could be obtained by concealment or warning

1. Geometrid moths mimic the pattern of dead leaves.

2. Lichen Katydid lives surrounded by the lichen on which they feed and has evolved an appearance of spiny processes and wing venation that that duplicates lichen's appearance

3. In glass wing butterfly *Cithaerias sp.*- a false eye spot located on the edge of the hind wing which prevent attack by bird.

4. The tent bat *Ectophylla alba* chew the leaf veins of heliconias on the either side of midrib causing the leaf to fold down thus creating shelter from sun and rain and reducing exposure to predators.

5. The flat footed bugs produces noxious, malodorous secretions when disturbed and their specialized colourful hind legs makes it easy for predators to avoid them.

6. The bold pattern of freshly emerged passion vine butterfly is a form of warning coloration that advertises unpalatibility.

7. The palatable viceroy butterfly *Lementis sp.* can easily be preyed upon, thus it mimics the non palatable monarch butterfly.

Adaptations for prey capture :

1. The green palm viper (*Bothrops sp*) and the golden eye lash viper (*B. schlegelii*)are able to hunt at night using the large loreal pits located ahead of their eyes. These organs are effective in targeting small mammals while tree snake (*Imantodes sp*) instead relies on its huge eyes to locate prey at night.

2. The blunt headed tree snake (*Imantodes cenchoa*) has a uniquely constructed backbone that enables it to reach across wide spaces without support - an adaptation useful for preying upon sleeping lizards.

3. The eyelash viper has a molted skin pattern that makes it difficult to see - an excellent strategy of camouflage for life as a sit and wait predator that feeds on small rodents, frogs, lizards.

4. Vine snakes (*Oxybelis sp*) possess an extremely thin elongate green brown body, a combination that provides while they hunt through tangled vegetation in search of food.

5. The huge eyes of many rainforest frogs (eg. *Agalychnis sp*) enable them to hunt at night. Some others like transparent glass frog (*Centrolenella sp*) avoids bright tropical sun and are active on wet warm nights.

6. The male strawberry poison tart frogs wrestle on the forest floor for control over territory their bold colors advertise their toxicity to their would be predators.

Adaptations for arboreal mode of life :

1. In the porcupine (*Coendou mexicans*) prehensile tail helps to support its full weight. The spine free underside of the tail enables it to grasp branches securely when feeding at the edge of tree crown.

2. In highly mobile spider monkeys (*Ateles sp*) the dexterous tails act as fifth limb enabling the monkeys to dangle at the very tip of branches where flowers and fruits are located.

3. One of the most common arboreal mammals the Kingkajou (*Potas flavus*) is among the few carnivorous that have specialized in fruit diet. The prehensile tail allows it to make greater use of its fore limbs for plucking and handling fruits.

4. Sloths are superbly engineered for a life time of suspension hanging upside down high above the forest floor. The adaptive elegance of sloths have been an almost catatonic accident of nature. Their various anatomical adaptations are :

(a) Small animal, light weight.

(b) Strongly built chest ribs and limb girdles.

(c) Thorax subcircular and ribs more curved.

(d) Number of ribs increased to give support to the viscera during inverted position.

(e) Lumber vertebrae elongated and number has increased.

(f) pectoral girdles strongly built, as for limb support the body weight while hanging.

(g) The clavicle and scapula are prominent to withstand the strain of contraction of powerful breast muscles.

5. Syndactily found in Koala, where the2nd and 3rd toes are syndactylus.

6. In Chameleon the digits are arranged into opposable bundles of 2 or 3 digits in both fore and hind limbs to hold branches (grasping type).

7. Long, curved claws are common in bats, squirrels, lizards but modified into powerful hooks in sloths.

Different Types of Arboreal Animals are :

Branch Runner : Progression on the upper surface of the trees by both the pairs of the limbs, e.g. - Squirrels, Lemurs, Chameleon.

Suspended form : hang head down from the branches, unable to walk on the branches. Move while suspended upside down. Clinging on the branches with claws, e.g. - Bat, Sloth etc.

Branchiator : Move from branch to branch swinging forelimbs with great speed and accuracy, e.g. - Apes, monkeys.

12.3 Desert biome

Desert is the arid region of the earth surface, where rainfall and moisture are insufficient to support normal life. In these regions average rainfall never exceeds 10-15 inches per year. Depending upon rains deserts can be categorized into :- (a) low rainfall deserts e.g. -Atacama, (b) cold deserts such as Alps and Scandinavian mountains, (c) hot deserts of equatorial regions, (d) low nutrient deserts such as North American deserts (e) high salt deserts found in Chile, S. America and Australia.

1. Characteristics :

- Scarcity of water : This is due to rainfall and absence of natural sources of water.
- Extremes of Temp : The temperature in the day time is very high and relative humidity is very low. During night the temperature goes down tremendously because of the radiation of heat into space.
- Dust storms : Lack of moisture and extreme of temperature cause an increase in the air movement and dust storms in every evening..
- Lack of vegetation : Due to scarcity of water , plants are unable to grow. The vegetation is also modified for this mode of life being succulent and thorny, which prevents excessive evaporation of water.

2. Faunal Makeup :

- Under the harsh and shimmering sun the arid backed sand of the desert may appear to be devoid of animal life, but surprisingly large numbers of animal species thrive there. These are either drought evaders or drought resistors.
- They make their appearance only when rain sets in, for the rest of the day they remain dormant either in egg or pupal stage.
- Insects like crickets, grasshoppers, ants, bees, wasps, butterflies, moth and beetles swarm in the desert, when rain arrives and plants flourish.
- Tiny shrimps appear in temporary ponds.
- Lizards and snakes are also very common.
- Birds are few and live in places which have surface water for drinking within their flying range.
- Small rodents like kangaroo rats, pocket mice, desert mongoose, desert fox, desert hedgehog, kit-fox, jack rabbit and the camel, deers, antelopes, and asses are the mammalian forms found in the desert.

3. Adaptations :

The fauna of desert is peculiarly adapted to these drastic conditions and the modifications are mostly associated with the conservation and availability of water, protection against extreme heat and cold and obtaining food.

(A) Adaptations for obtaining water :

- Higher animals cannot live long without drinking water and need water at frequent intervals. Therefore, desert animals try to utilize water from every available source.

• A few animals absorb dewdrops along with plant food.

• Certain desert animals such as desert rabbit, turtles and wood rat do not drink water even it is available to them. These suffice their need by eating succulent plants.

• The most specialized group of animals (ant and rats- Jerboas and kangaroo rat) depends entirely upon metabolic water produced in their body during the oxidation of foodstuffs.

• Carnivorous animals get needful water from the body of their prey.

• Skin like certain animals like *Moloch* is hygroscopic and absorbs water like a blotting paper.

(B) **Adaptation for Conservation of Water :**

Terrestrial animals may lose water from their body in three ways :-

a. By evaporation, through the body surface.

b. By exhaling moisture during respiration, and

c. By expelling water or liquid urine during excretion.

a. To avoid evaporation through the body surface- Desert animals have developed several protective measures, such as -

• Development of thick hides which water loss by perspiration.

• Number of sweat glands in the skin of desert mammals is very much reduced or in some cases they are totally absent.

• Scorpions and reptiles have developed almost impermeable outer covering. Sometimes, scales and spines are developed in the exposed surfaces, e.g. - sand lizard (*Moloch*) and horned toad (*Phrynosoma*).

• Some desert animals produce epiphragms and secretions to prevent loss of water. Desert insects are wax-proof.

• Camels have developed more tolerance to heat. Their body temperature fluctuates more with the atmosphere and thus reduced the amount of moisture loss through sweating and panting.

b. To avoid loss of moisture during respiration- many desert mammals cool the exhaled air in their noses, before it is expelled out through nostrils. As a result moisture condenses in the nose and is not lost as water vapours along the exhaled air.

c. To avoid loss of water during excretion- this is brought about by excreting concentrated urine or urine in semisolid state. Desert rats and kangaroo rats excrete urine which contains 24% urea, whereas in man urine contains just 6% urea. Even reptiles, insects and birds pass their body wastes in such concentrated state as uric acid that little or no moisture is lost in the process.

(C) **Protection against heat/cold :**

- Desert animals have thick hide or have protective armour of scales, spines or dermal scutes.

- Desert animals have long legs, which no doubt help in jumping and swift running, but also lift the body above the ground and thus avoid direct contact of the body with burning sand, e.g. - kangaroo rat, Jerboa etc.

- The desert animals hide themselves in the burrows during day time and come out only late in the evening and at night or early in the morning when temperature is low and relative humidity is high in the air.

- The other animals that can not remain in the burrows hide themselves under some suitable shelter and avoid the scorching sunrays of the noon.

(D) **Protection against sand storms :**

- Nostrils in majority of desert animals are either reduced to small pinholes or they are protected complicated valves. For example in Camel, the nostrils can be closed in the same way as eyes are closed by the eyelids.

- Eyelids exhibit various modifications and are capable of closing the eyes without hindering the vision. In Camel the eyes are high on the head and are protected by long and thick eye lashes.

- Ears are often protected with fringes of scales or hairs. In *Phrynosoma* the ear apertures are absent. Nocturnal animals need a sharp sense of hearing. Jack rabbits, hare have large ears.

(E) **Swift running or speed :**

- Since desert animals have to move far in search of food and water, majority of them have great speed. Also the limbs are specialized and adapted to walk on sand.

- In leaf hopper and kangaroo rat the limbs are long.

- Desert cat has wide soles thickly covered with fur which enables it to walk comfortably even on hot sand.

- Legs of ostrich are padded with heavy callosities.

- The undersurface of camel's feet also padded.

(F) **Colour :**

The colouration in desert animals is dull and is found to match with the sand-dunes. The body hues vary from grey, brown to red and are less heavily pigmented. This type of colouration helps the animals in camouflaging. Warning colouration is exhibited by poisonous animals like lizards, Heloderma, rattle snake, spiders and red ants.

(G) Spinescence :

The spine studded body is characteristics features of many desert animals like *Moloch horridus* (flat spiny lizard), *Phrynosoma* (horned lizard) etc.

(H) Venom :

Possession of venom is another attribute to desert animals. Rattle snakes, trap door spider and Tarantula are poisonous *creatures of the desert.*

(I) Sense Organ :

Organs of sights, smell and hearing are specially developed.

12.4 Marine environments

The sea covers about 70% of the earth's surface and is great reservoir of life. Among the three major habitats of the biosphere marine realms provide the largest inhabitable space for living organisms.

1. Characteristics :

Temperature :

Ocean is the largest store house of the sun's heat and it occupies much space. The extremes of temperature ranges from 3°C to 40°C, while in the Indian seas the temperature ranges between 18°C to 25°C at the surface. The density of the sea water and solubility of oxygen increases with decrease in temperature.

Salinity :

The salinity of the open ocean at about 300 meters depth is about 3.5%. There is slight variation in salinity in some seas, such as- in Mediterranean Sea it is 3.95% and in Red Sea it is 4.6%. The sea water is weekly alkaline (pH 8 to 8.3) and strongly buffered. The salinity of the sea is due to two elements - Sodium and Chlorine which account of the 86% salts of the sea. An increase or decrease in the salinity brings about changes in specific gravity of the sea water.

Light :

On the basis of the penetration of the light the ocean is divisible into two zones :-

The lighted or littoral zone : The littoral zone extends upto the outer edge of continental shelf (around the continents below sea level a small portion of the ocean bottom forms a shallow platform, called continental shelf) and roughly upto the depth of 200 meters. The littoral zone of the sea is broadly divided into supralittoral, intertidal or eulittoral and subtidal or sublittoral zones. The supralittoral zone is the uppermost of the all littoral habitat and in the beach down to the edge of the sea. Below this zone is the eulittoral zone which is represented by the intertidal zone (zone between high tide and low tide) of the continental shelf. Below the intertidal zone is the sublittoral zone which extends from low water tide mark to about 200 meters.

The deep sea system : Comprises of three main zones - bathyal, abyssal and hadal zones respectively. The bathyal zone extends onto the continental shelf where the ocean descends rapidly from 200 meters to about 4000 meters. From 4000 meters to 6000 meters is the abyssal zone covering the entire ocean floor. In the trenches of the ocean, the sea is as deep as 10000 meters. This region is called as hadal zone.

Pressure :

Pressure affects marine animals in various ways. The deposition of calcium is difficult at heavy pressure. Carbon dioxide accumulates in high pressure and makes calcium carbonate more soluble.

Waves :

The waves have their maximum effect in the intertidal zones. The maximum height that is normally reached by the waves in the ocean is 17 meters. When the waves strike, the impact is very heavy and can even turn huge stones. The force of impact of the waves is roughly about 1.5 kg per sq. Cm.

Tides :

The tides are caused by the gravitational pool of the moon and sun on the waters of the ocean. The tides may appear once in 24 hours or once in twelve and half hours.

Currents :

The sea is in continuous circulation. Air temperature differences between poles and equator set up strong winds which create definite currents in the ocean. Because of the circulation oxygen depletion is so common in freshwater lakes and very rare in oceans.

2. Faunal Makeup :

Fauna of the Littoral Zone :

The eulittoral zone is the most favourable of all the habitats afforded by sea. Due to abundance of light, water, oxygen, carbon dioxide and less salinity of water, the tidal zone is characterized by dense growth of vegetation which provides shelter and food for animals. Animals of every phylum of animal kingdom are represented in the region and are mostly sedentary and sessile.

The rocky shores are inhabited by a large number of sessile animals. Many sponges and coelenterates abound here. Among the molluscs *Chiton, Patella, Nerita, Oysters, Mytilus* etc. are very common. Also here is predominance of boring invertebrates like *Pholas, Teredo* and *Lithodomus*. Echinoderms, especially sea urchins and star fishes are sometimes found here.

The sandy shores usually have a lot of sea weeds and form an ideal place for many animals to live and hide in between them. The fauna includes protozoans, turbellarians, nematodes and copepods. Certain fishes bearing rostrum such as *Hemiramphus, Belone* etc. plough the sand in search of prey. Protochordates like *Balanoglossus* and *Amphioxus* are major sand dwellers.

In the muddy shore there is abundant supply of food due to plenty of dead organic material along with bacterial populations are inhabited by a large number of protozoans, nematodes, small Crustacea, amphipods, isopods and ostracods. Many molluscs bury themselves inside the mud while soft bodied nudibranchs move over the surface. Among the fishes Boleopthalmus and Periopthalmus are common.

The bottom fauna of sublittoral zone consists of several types of foraminiferans, sponges (*Clione*), segmented worms, coelenterates (sea-pen, sea-fan etc.), sipunculids, crustaceans, star fishes, brittle stars, sea urchin and sea cucumbers, stone crabs, spider crabs, hermit crabs and rock lobsters are also found. The most characteristic feature of sublittoral zone is the presence of coral reefs.

Fauna of Deep Sea :

In spite of the hostility of the deep sea atmosphere, almost all the phyla (except air breathing arthropods and land vertebrates are represented in deep sea.

Protozoa : Radiolarians and Foraminiferans occur abundantly in archibenthic and abyssal benthic zones respectively.

Porifera : Glass sponges of class Hexactinellida occur almost exclusively in deep sea being fixed to the sediments by long root spicules.

Coelenterate : Stony corals, few soft corals like sea-pens, sea-anemones and gorgonids are found in deep sea.

Annelida : Annelids are mostly littoral but tube dwelling polychaetes like *Chaetopterus, Sabella, Serpula* etc. often found.

Arthropoda : A few of the arthropod groups such as barnacles, isopods and amphipods are found at the sea bottom. Crabs, lobsters and shrimps are very common in the abyssal water. *Limulus* (king crab) is the only arachnid found in deep sea habitat.

Mollusca : Almost all the classes of Mollusca are represented in the deep sea. Chitons, bivalved and single valved molluscs i.e. Lamellibranchs and gastropods all occur abundantly.

Echinodermata : Echinoderms are most numerous in deep sea habitat. Stalked crinoids are exclusively deep sea animals.

Fishes : *Chimera* and *Hariotta* are from deep sea. Teleosts fishes like *Photostomias, Idiacanthus, Gastrostomus, Cryptoceras, Bassogigas, Bathypterois. Lesiognathus, Malacostus, and Gigantactis* etc. are from deep sea. All the flat fishes belonging to order Heterostomata are exclusively deep sea fishes found at the bottom.

3. Adaptations :

Adaptations found in Littoral Zone animals :

The animals of rocky shore have developed following adaptations for attachment and protection from desiccation of feeding :-

1. Mostly these animals are sessile because rocks provide them secure places for attachment.

2. Because of sedentary mode of life several morphological changes have taken place in these animals-

- Loss of locomotory organs, e.g. - Mytilus and *Ostrea*.
- Mouth and anus at the same level, e.g. - Ascidians and Polyzoans.
- Development of efficient sense organ as in tube dwelling polychaetes.
- Development of thick test as *Balanus*, Bivalves and Ascidians.
- Development of ciliary mode of feeding.
- Power of reproducing by budding thereby, forming large colonies, e.g. - *Botryllus*.

3. To conserve water and to avoid desiccation, sedentary animals have developed tube dwelling habit which also help them in escaping from the impact of waves and from predators.

4. The animals living in the exposed rocks have developed various defensive mechanisms such as spicules in sponges and stinging cells in coelenterates. Many snails possess spiny shells.

5. To reduce friction, many rocky shore animals have flattened body such as *Oscarella*, leaf-like Turbellarians, Tunicates (*Botryllus*) and certain crabs.

6. Some rock inhabitants have developed protective resemblance. *Octopus* which is found in crevices among stones often resembles the colour of the stone.

Most of the marine sand-dwelling forms are burrowing in nature. They show following adaptations for successful living in the sandy sea shore.

1. To escape from the action of waves, evil effects of desiccation, lower salinity and extremes of temperature most of the sandy shore animals lead a burrowing mode of life.

2. Due to burrowing mode of life these organisms have developed certain devices such as digging organs, ciliary mode of feeding and certain respiratory devices.

3. Burrowing molluscs have developed long siphons.

4. The fishes *Trachinus* and *Uronoscopus* which bury in the sand do not have air bladders.

5. Burrowing annelids have lost their parapodia.

6. Fishes that feed on the sandy shore fauna have elongated jaws which are used to plough the sand.

Muddy-shore animals show following adaptations for successful living -

1. The colouration of mud-dwellers are yellowish grey or white.

2. All mud-dwellers are soft bodied and the body musculature is generally weak. If they possess shells, then they are very thin.

3. In the case of molluscs the siphons are very long.

4. Sense organs like eyes are degenerated or absent and the nervous system is poorly developed.

5. The foot of animals like *Aplysia* is very broad and prevents sinking while moving over sand.

6. Mud animals possess special structures to provide respiratory currents and also have specialized organs for digging purposes.

Deep Sea Adaptations :

1. Size : In general, deep sea organisms are relatively smaller than their relatives on the surface. *Chimera* (Holocephali) and *Scapanorhyuchus* (shark) are two exceptions to this rule. Scarcity of food explains for their small size.

2. Form : Body of deep sea animals is observed to be delicate and slender, because the struggle for existence is absent and the water at sea bottom is perfectly calm with no movement. Some deep sea fishes are so much laterally flattened that the eye of one side comes to lie on the other side and body becomes band or ribbon like.

3. Skeleton : Skeleton of deep sea forms is soft and noncalcareous, because they are unable to synthesize Calcium at low temperature. For this reason calcareous sponges are completely absent from deep sea. The protozoans and corals have exoskeleton of silica. Deep sea molluscs have fragile shells and fishes have either sparsely calcified or totally uncalcified (*Chimera*) endoskeleton.

4. Colour : due to complete absence of light the deep sea forms exhibit uniform colour pattern. These may be red, brown, black, violet and blue etc. but red colour predominates.

5. Food & Feeding : vegetation is absent in the sea bottom. Therefore deep sea animals have three alternative source of food :

- Prey upon one another.
- Depend on the falling excreta of the surface animals.
- Depend upon surface plants and animals which sink to the bottom.

Most of the deep sea animals are predatory. The predaceous animals possess powerful jaws and strong, sharp teeth. The stomach is much distensible that sometimes it contains prey even larger than the size of animal.

The vegetarian animals of deep sea have elongated alimentary canal and a reduced radula. In addition they are characterized by the possession of an elongated excretory tube which carries the excreta away from feeding place of the animals so that it is maintained clean.

6. Bioluminescence : The phenomenon of production of light is most widespread in deep sea forms. It is very common among fishes, Crustaceans, Cephalopods, many Coelenterates, some star fishes and few annelids. Bioluminescence can be useful to deep sea forms in recognition of sex and attracting the prey.

7. Eyes : Mesopelagic animals of the deep sea have large eyes like that of the terrestrial twilight animals like Geckos, owls and the Loris. The deep sea fishes have more rods while cones are either reduced or absent. The eyes are completely absent in *Pecten* and *Eulemia*.

8. Sensory Organs : In deep sea crustaceans the loss of sight is compensated by the development of long feelers or antennae. Even those animals which have well developed sight the antennae are of unusual length. In deep sea fishes the fin rays are considerably elongated (e.g. - *Bathypterois*, one fin ray of the pectoral fin is produced in a sensory filament). These structures are sensory to touch and perceive slightest disturbance in the surrounding water.

9. Lateral-line System : In the deep sea fishes the lateral-line system is very well developed to compensate for the sight.

10. Mucous secreting glands are presenting all deep sea fishes.

11. Low Metabolic rate : The deep sea animals usually have very low metabolic rate due to the prevailing low temperatures.

12. Sexual Adaptations : Deep sea population is very thin and it is difficult to find mates. In Angler fishes the males are small and are attached to the females during breeding season. In *Edriolychnus* the tissue of both the sexes are fused and the blood stream is also connected. The barnacle *Scapellum* has complementary males.

UNIT 13 ❑ Wildlife Conservation

Structure

13.0 Introduction

13.1 Necessity and objective of wild life conservation

13.2 Categories of endangered animals and red data book

13.3 Wild life census

13.0 Indroduction

Conservation is the management of natural resources both living and non-living in such a way so as to yield the greatest sustainable benefit to the future needs and aspirations of the mankind. It is also referrred as an insurance policy for the future.

13.1 Necessity and objective of wild life conservation

13.1.1 Necessity for Conservation :

Balance of Nature :

Each biotic components by virtue of its position in the food chain maintain the delicate balance of an ecosystem. If a species is lost, it may upset the balance of Nature - makes the system vulnarable. The destruction of carnivores will help the increase the herbivores which in turn will affect the forest vegetation. Once the forest vegetation is reduced, herbivores will invade cultivated lands. The reduction in the extent of the forest will affects rains and thereby affects the economy of our land. Sometimes if tiger turns man eaters and hyenas become child lifters, it is because man has interfered with their natural food.

Economic value :

The animal products like hides, horns, ivory, fur etc. are good source of income for our country. Much revenue is realized by way of fees for the license to shoot and also as duty imposed for the import of arms and ammunition. The collection and supply of live and dead specimen to the zoos and museums also bring in lot revenue.

The wildlife wealth can be used as a source for increasing our earnings on tourism.

Scientific Value :

From time immemorial, animals and birds have provided example and incentives to man for gaining mastery over his environment. The efficiency of new medicines or any new surgical method is often tested on animals, for example, the common Rhesus monkey has been subjected to such many tests. The preservation of wildlife will help many naturalists to study the animals in close quarters.

Game Value :

The wildlife of our country is a source of sport and enjoyment. It gives healthy recreation to people of all walks of life. Bird watching is a very popular pastime among many foreigners. A visit to the Sanctuaries and National Parks can become a regular schedule for school children and college students. It is a thrilling experience to see these animals in close quarters and especially in their natural surroundings.

Cultural Value :

The wildlife of India has got interwined with our culture. The early Indus civilization shows the use of animal symbols in their seals. Our mythology and literature are full of accounts of these animals.

Religious Attachment :

An important place of honour has been given to animals in the galaxy of Hindu gods and their associates.

To Protect our Civilization :

One of the causes attributed by Historians for the culmination of the Mohenja-daro civilization was the absence of protection to wildlife. The people of that era were good hunters who waged a relentless war against the carnivores which resulted in the increase of herbivores. The enormous number of herbivores that were present reduced the forests and grasslands causing the advance of deserts and the end of an enviable civilization.

Genetic Resources :

It is require for advantageous characters like disease resistance, higher production or other desired characters.

Aesthetic Value :

For natural activities of colourful and melodious birds and mammals, thick forest belt become a source of pleasure and happiness.

13.1.2 Objectives of the Conseravation :

Conservation is chiefly concerned with the protection, preservation, preparation and judicious control of populations for rare species of plants and animals in their natural habitats. Intelligent exploitation of nature with all its biological and physical components in its original form as far as practicible. Actually conservation of wild life is equated with the proper management of nature. Conservation require for the folowing purposes-

1. To protect and preserve the rare species of plants and animals from extinction.
2. To preserve the breeding stock.
3. To prevent deforestation
4. To study the relation of plants and animals in their natural habitat.
5. To maintain the balance of nature.

For the above purpose several strategies have been employed like :-

Conservation through laws : To stop illegal hunting, poaching, trade, over exploitation of nature several laws are introduced such as Indian Wildlife (Protection) Act, 1972 which was amended in 1983, 1986 and 1991 respectively; Madras Wildlife Act, 1873; All India Elephant Preservation Act, 1879; The Wild Birds and Animal Protection Act, 1972 etc.

Establishment of more amenity areas : There are a chain of 93 National parks, 500 Sanctuary, 14 Biosphere Reserve and 28 Tiger Reserve in India for conservation of different animals.

Species Presevation Scheme : Special conservation programme for some threatened animals were granted. Such as Tiger Project, Operation Rhino, Gir Lion Project etc are running.

To Prevent Deforestation : afforestation schemes were introduced.

Habitat improvement : It can be done through-

- Improving structure of food chain.
- Nourishing fodder grasses and food plants.
- Providing more water holes, salt licks in the wild.
- Research on ecological requirements of wild animals and their documentation.

Periodic Census : periodic census of different wild animals are necessary to understand the trend in population - decreasing or increasing.

Preservation of Breeding Stock : It is done by artificial stocking of wild population in captive areas (by developing Captive Breeding programmes). This process is very difficult and expensive too.

People's participation :

For achieving success in conservation programmes it is very necessary to make aware the common people. It can be done by—

- Educating common people with the consequence of wild life loss.
- "Wildlife conservation and its benefit to the Society" be included in school/ college curricula.

13.2 Categories of enderngered animals and red data book

13.2.1 Categories Of Threatened Animals (IUCN) :

To highlight the legal status of threatened species for purpose of conservation, the International Union for Conservation of Nature and Natural Resources (IUCN) (1984, 1988) has established the following five main conservation categories.

Extinct : species that are no longer known to exist in the wild. Searches of localities where they were once found and of other possible sites have failed to detect the species.

Mountain Quail (*Ophrysia superciliosa*)

Asiatic Cheetah (*Acinonyx jubatus*)

Critical : Facing an extremely high probability of extinction in the wild in immediate future.

e.g. - Yak (*Bos mutus*)

Sangai (*Cervus eldi*)

Black necked Crane (*Grus nigricollis*)

Endangered : species that have a high likelihood of going extinct in the near future.

e.g. - Himalayan Newts (*Tylotoriton verrucosus*)

Lion-tailed Macaque (*Macaca silenus*)

Hoolock Gibbon (*Hylopetes hoolock*)

Adjutant Stork (*Leptotilos dubius*)

Vulnerable : species that may become endangered in the near future because populations of the species are decreasing in size throughout its range.

e.g. - Slender Loris (*Loris tardigradus*)

Langur (*Presbytis* spp.)

Whistiling Teal (*Dendrocygna bicolor*)

Rare : species that have small total number of individuals often due to limited geographical ranges or low population densities.

e.g. - Giant Heron (Ardea *goliath*)

Insufficiently Known : species that probably belong to one of the conservation categories but are not sufficiently well known to be assigned to a specific category.

e.g. - Andaman Wild Pig (Susscrofa *andamanesis*)

Tibatan antelope (*Pantholops hodgsoni)*

13.2.2 Red Data Book :

International Union for Conservation of Nature and Natural Resources (IUCN), also known as World Conservation Union, with Headquarters at Gland, Switzerland, has established the six main conservation categories. Using the IUCN categories, the World Conservation Monitoring Centre (WCMC) has evaluated and described threats to about 60000 plant and 2000 animal species in its series of Red Data Books. The great majority of the species on these lists of Red Data Books are plants. However, there are also species of fish, amphibians, reptiles, invertebrates, birds and mammals. The IUCN system has been applied to specific geographical areas as a way to highlight conservation priorities.

To help focus attention on the threatened species most in need of immediate conservation efforts, IUCN has begun to issue lists of the world's most threatened plants and animals. These lists include species of unique conservation value. On a global basis, the IUCN have estimated that about 10% of the world's vascular plant species totaling of about 20000-25000 species are under varying degrees of threat. IUCN published the "IUCN Red List of Threatened Animals" for the first time in 1988 and "IUCN Plant Red Data Book" in 1978.

In India, the problem of threatened plants was first discussed in the 11th Technical Meeting of the IUCN in 1969. In 1980, the Botanical Survey of India (BSI) published a small booklet entitled "Threatened Plants of India - A State-Of-The Art Report". The first volume of Red Data Books on Indian Plants was published by Botanical Survey of India in 1987; it includes 235 vascular plant species of Indian flora.

13.3 Wildlife census

13.3.1 Objective, Comprehensive knowledge on direct and indirect census techniques

Objective of Census

- An estimation of the total number of a particular animal population present in a particular area in a particular time. It is not absolute, but relative one.

- To determine trends in population - whether increasing, decrescasing or stable.
- It indicate the change of population with time.
- To draw comparison between areas, seasons or treatments.
- To compare the situation before and after mangement intervention.
- Comprehensive Knowledge on Techniques

1. Selection of a appropriate technique : It depends upon the following points.

- Area to be surveyed
- Species to be censused
- In which season the animal will be censused?
- Direct or indirect census technique will be adopted.

2. Which species is to be censused?

For management purpose it is obviously impossible to census all species in the area concerned. Therefore it has to make a choice such as one the following :

- Species which require management intervention (over grazing, competition)
- The species should be nationally or internationally endangered.
- The species should have either economic importance or is a important prey species.
- The species should have tourist attractions.

3. Selection of proper timing : It depends upon the following criteria

- Type of census.
- The reason for which the census operation is being conducted.
- Visibility of habitat varies with season.
- In case of water- hole census- dry season is best.
- Period of disturbance such as tourist season, fire, timber working etc. must be avoided.

4. Types of Census : There are two types of census :

Direct census technique : It is applicable to those animals which have relatively high densities and can be seen directly. Generally medium to large sized ungulates rhino, elephant are censused through this technique.

Indirect census technique : It is applicable to those species which have very low densities, difficult to see because of poor habitat visibility or cryptic behaviour. It is appilicable to carnivores, small, nocturnal mammals and also large mammals in dense habitat. Generally dung, pellet, nests, burrows, pugmark count comes under this category. Indirect census technique rarely yields a good estimate of actual population.

13.3.2 Sample count, line transect method, pug marking

TOTAL COUNT

For total count the entire area under consideration is searched. Major disadvantages of total counts are that maximum manpower is needed and one can not account for unavoidable errors. It is very difficult to treat the data statistically. Area size species, terrain, cover and available resources decide when a total count becomes prohibitively expensive or simply impossible.

SAMPLE COUNT

Here only a part of the area is counted (sampling unit). The cumulative area covered by these sample counts is a known (calculated) proportion of the total area, hence, the total [population size can be estimated by extrapolating the outcome of the sample count to the entire area. This population estimate can be subjected to statistical treatment, as the data are based on an independent count. By this way, there will be a maximum and minimum range within which the actual population size will fall. Sample counts are more efficient than total counts and can be repeated, which is the basis of monitoring.

A number of techniques have been suggested for estimation of population density of wild species which are varied and diverse, but none is so elastic to embrace all groups and all habitats.

LINE-TRANSECT METHOD

Line transect is one of the well known distance methods for sampling biological populations. This method has been used since early 1930's (Burnham et al 1980) for estimating the abundance of wildlife populations. It is not only practical and efficient but is relatively inexpensive too. It is based on the theory of walking along a predetermined route (at regular interval) to record the objects on or near the line.

Study Design :

Site Selection : Either random (stratified random) or systematic manner (stratified design) based on research goal and objective of the study.

Type of Habitat : Transects are well suited for open habitats and flat areas, but they have also been successfully tested in hilly areas both in India and other countries.

Placements of Transect : The marked transects is more or less straight so that there is no error in estimation of perpendicular distances and sighting of objects. Transects should also be well spaced out, distances between two parallel transects should be not less than 200m.Transects can be placed in random, stratified (acc. to habitat) and in piece wise_linear fashion in hilly and more rugged terrain.

Permanent Vs Temporary : If the aim is to monitor transects in different seasons and for successive years the transect line should be marked using boulders /stones or permanent posts such as trees.

Transect Length : Transects of up to 800m have been found to be adequate. Uniformity and extent of the vegetation type and topography can also influence the Transect length.

Travel Speed : While monitoring Transect one has to walk at a standard pace covering about 8-10m/min.Ideally a 1-1.5km long Transect should be covered in about 1-2hrs.All census operations should be conducted in the morning, which is the period of peak bird activity.

Time of the Day : At early morning, 10- 15 minutes after sunrise and for 2- 3 hours.

Weather Condition : Fair weather necessary and cloudy, windy and rainy days must be avoided.

Periodicity : Fortnightly or weekly monitoring of Transects is a standard practice. For long term monthly monitoring can be adopted.

Replicates and Number of Monitoring : Two replicates for a Transect are ideal in most cases, as often during analysis.

Data Collection :

Direct sightings or calls :

For each monitoring of Transects, perpendicular distances (PD), sighting angles (SA) and sighting distances (SD) can be recorded. In addition, other ancillary data for instance sex, age and group size can also be recorded for every bird detected.

Calls can also be recorded for density estimation. But based on the studies in Dudwa (SJ), we would like to caution the potential users of line Transects that there are chances of grater error in estimating densities from calls. The reason is that in field it becomes difficult to fix the call and hence cause the first error in estimating the perpendicular distance. Secondly, with call intensity and prevailing wind condition, one can easily ascribe call coming from different habitats to the habitat being sampled. And, lastly taking call cues for density estimates requires tremendous knowledge of the birds and their calls, not to forget that there are good imitators in the forest e.g. Redheaded Thrush and Racket-Tailed Drongo.

Variables to be recorded :

1. Perpendicular distance/sighting angle. At every detection, perpendicular distance of the object from the Transect line is recorded.

2. Bird species and their number.

3. Perch height or vertical distance.

4. Sighting angle.

5. Primary activity.

Biases :

Observer bias- employ same observer.

Habitat bias.

Bird/ animal behaviour.

Weather.

Advantages of Line-Transect :

Based on its versatility, easy monitoring, we list the following advantages associated with line Transect sampling :

More economical.

Greater species turnover.

Larger area is covered in relatively shorter time.

Applicable throughout the year.

Permanent Transects can be monitored for longer period of time.

Can be used in most of the habitat types.

With little care can also be used for hilly terrain.

Disadvantages of Line- Transect :

The line Transect method of sampling has certain disadvantages, which are not a great handicap if one looks at ease, usefulness and applicability of this method across a wide range of habitat and terrain types. Some of the disadvantages are :

Distances are not correctly measured.

Movement of observer may disturb the birds.

Chances of missing skulking, cryptic and shy birds are high.

Precautions :

For better results keep line as straight as possible.

Perpendicular distance should be measured correctly.

Transect should be representative of the habitats.

Observer must be trained, competent and interested.

PUG MARKING

There is no scope to enumerate Tiger by direct count. We all know that Tiger-sighting is heavily dependent upon "luck", and that, before we see a Tiger once, the Tiger would have seen us a hundred times. Yet, we know of signs that speak about the presence of Tiger. Some of the main evidences include kills, scat, pugmarks, ground-scratches, tree-scratches etc. Among all the field evidences, pugmarks are the most common, most revealing and easiest to use, verify and interpret to produce reliable information on minimum numbers of Tigers.

"Project Tiger" was launched in 1972 at the Dhikala Forest Rest House in Corbett National Park. The first all India Census of Tigers was conducted in summer 1972 using Chaudhury's method of Cooperation Tiger Census with the Tiger Tracer. The method has been in use since then but not without national and international doubts about the figures which was achieved for the Tiger population.

In the 1990s, a fresh spate of doubt arose about the number of Tigers in India. In the process, the technique of Pugmark Tracking was attacked in the media.

(I) Requirements for pugmark tracer :

1. 1 pane of colourless glass with holes drilled at the corners.

2. Metal screws with nuts and washers to fit (these are legs of tracer).

3. Thin paper to transfer the tracing from glass to paper.

4. Rubber band, felt pen, measuring tape.

(II) Selection of track for tracing :

1. A well formed impression of the rear pug from a series of tracks should be selected.

2. If no perfect impression is available a composite tracing should be made using 2 or 3 pugmarks of the same animal.

3. Left and right pugs should be identical mirror images.

4. Front pug is larger than the rear pug. Middle toes in front pugs come to same level.

5. Decision should be made earlier whether left rear or right rear pugmark is to be traced.

(III) Tracing the track :

(A) The procedure :

The tracer should be placed directly above the clear track. The legs of the tracer is pushed inside the soil until the glass pane is above the track surface. If the ground is hard the glass pane should be lowered by adjusting the wing nuts. With both the knees on the ground, left and right of the tracer and by looking straight down tracing should be started. Parallax should be avoided to get an accurate tracing.

Next the tracing paper is attached to the glass by means of rubber bands and by holding it against light the outline of the pugmark is transferred from glass to tracing paper by avoiding parallax. Other information to record :

Name of researcher.

Date and time of tracking.

Direction of movement.

Location eg. section of road.

(B) **Measurements :**

1. Lines are drawn on all sides of the pugmark touching the edges, thus forming a quadrangle.

2. The lines are at right angles to each other.

3. The center of toes and pad are marked.

4. The vertical distance i.e. Pad to toe length is called Pugmark Length (PML).

5. The horizontal distance i.e. Toe to toe length is called Pugmark Breadth (PMB).

6. Distance between center points of toes are measured. It is called Toe to Toe Breadth (TTB).

7. Distance between center points of toes and the center point of pad is called Pad to toe length.

(C) **Step and stride :**

Step is that particular distance covered by two consecutive legs (left and right) during walking. Stride is the distance between same-sided legs during walking.

(IV) **Timing of survey :**

1. If an estimate of population size and structure is the only purpose, survey should be done for several weeks when tiger tracks can be conveniently located.

2. In order to locate home range and habitat utilization within a given area the survey should be extended through a full season.

3. The pugmarks records obtained are compared every day and individual locations are entered in a map. In a few weeks these will lead to identification of all individuals using the area.

(V) **Interpretation of track data :**

Distinguishing characters

Male tiger	Female tiger.
The quadrangle is a square or almost a square. PMB=PML. The PML > 12 cm.	The quadrangle is a rectangle. PML>PMB. PML is 9.5-12 cm.

Pugmarks of cat family Impression of pad and toes present	Pugmarks of dog family Impression of claw along with that of pad and toe present.

Pugmarks of :	**Adult male tiger**	**Adult female tiger**	**Tiger cub**	**Leopard**	**Leopard cub**
Pugmark length :	>12 cm	9.5-12 cm.	Upto 9.5 to 10 cm.	5 -9.5 cm.	Upto 5cm.

Pugmarks of tiger cub	**Pugmarks of leopard**
PML 9.5-10 cm and found with pugmarks of adult female in the vicinity because cubs are associated with the mother	Only one type of pugmark of 5-9.5 cm PML is found without any other type of pugmarks. Leopard cubs are still smaller accompanied by their mother.

Once the pugmark of an animal is positively identified it should be given a number so that it can be remembered and referred to. The number can be pinned to a map to indicate locations where its track has been located. This will show the general whereabouts of the animal during the survey.

(VI) **Precautions :**

1. Pre-caution should be taken for multiple tracks.

2. Proper decision should be made to discriminate a tiger and a leopard track - it is difficult to discriminate the tracks of young tigers (six months or less) from those of leopard tracks, however tiger cubs of that age are always accompanied by their mothers.

(VII) Subjects of main criticism :

1. **Population growth rate presented in the initial years and its agreement with natality/mortality figure for tigers** : After about ten years of Project Tiger estimates indicated that the Tiger population had increased in almost in all habitats. This situation was varied with suspicion, and it was argued that the population estimates were not correct.

However, now it is agreed that it is indeed possible to estimate whatever the population growth rate has been.

2. The claim that by using pugmark technique we are identifying individual tigers : It has often been claimed that we always identify all individual Tigers from pugmarks. This claim is a little premature and needs to be properly explained. In fact, such identification of individuals is necessary only in a limited number of instances. It is necessary to establish the identification of two Tigers if they have pugmarks of equal size and obtained from two adjoining census units. Where separate identity is not distinct, it is always safe to state the two evidences belonging to one Tiger. Moreover, we are aiming to arrive at the minimum size of the Tiger population.

3. Pugmarks varying on different ground condition : Pugmark impressions vary in depth, size and clarity depending on ground conditions. Therefore, soil-conditions have to be taken into account and the actual tracing of the pugmark has to be determined. Pug Impression Pads (PIPs) with about 1cm layer of fine dust of soil provide a very stable and uniform ground condition.

4. Tracing varying from person to person : Field staffs of Forest Department do Tiger tracking and pugmarks tracings. The staffs are often knowledgeable about wildlife but are not always good at tracings.

5. Interpretation varying from person to person : The most commonly cited criticism is about an experiment where a selected few individuals were asked to determine the number of Tigers from a particular number of plaster casts. It is said that different individuals gave different results. The above situation arose because field data and analysis were incomplete. It is always necessary that information about field conditions and movement of Tiger have to be there to aid in analysis. These aspects have been taken care of in a prescribed format.

6. Underestimation of the number of cubs : By this technique we can identify one, rarely upto to three cubs. Therefore, the number of tiger cubs is underestimated.

7. Distinction of male and female : Male and female Tigers are distinguished on the basis of the quadrangle into which their hind pugmarks may fit. The contention had been that, if the pugmarks fits into a square it is male, otherwise it is female. Since it is rare event to have a perfect biological square, there have been arguments about sex-interpretation.

8. Distinction of tracks of tiger cub and leopard adult : The size of the pugmark of Tiger cubs and adult Leopard is almost the same but they differ in proportionate size of the toes and their arrangement. But distinguishing this requires experience.

9. Inadequate experience about the significance attached to population figures : This situation, if it is there, has definitely changed due to criticisms in the media, better standardization of the technique, and introduction to staff at all levels.

(VIII) Improvements made :

A number of aspects of the pugmark technique have been improved since 1990. Broadly, these aspects relate to the following :

A. Clarity and transparency has been introduced through non-official participation.

B. Simplification of the procedure has been made to make it intelligible to all field-level staff.

C. There is now adequate verifiability through lying of PIP (Pug Impression Pad).

(i) Season/unit/route/PIP

(ii) Data collection procedure

(iii) Training need

(iv) Analysis procedure

(v) Data presentation

D. The entire procedure is available in print in English and Hindi

E. Illustrated Pocket Books are being made available to field level workers.

F. A beginning has also been made to make available the procedure in local languages.

G. An experimental approach has been made to develop a video film in local language for use during training.

H. Printed materials have been produced in various forms like Trainer's Reference Sheets, Tracking guidelines and a Pictorial Field Guide for Forest Guards.

(IX) Significance :

If practiced well, the Pugmark technique can lead us to :

- Identify species.
- Identify sex.
- Identify major age classes (population composition).
- Link male-female/mother-cub.
- Develop map showing territorial distribution and areas of movement.

UNIT 14 ❑ Special Projects for Endangered Species

Structure

14.1 Himalayan Musk Deer

14.2 Manipuri Brow Antlered Deer (Sangai)

14.1 Himalayan Musk Deer *(Moschus chrysogaster)*

Taxonomic position :

Order - Artiodactyla

Family - Cervidae

Intraspecific Varieties :

Taxonomy rather disputed - due to wide ecological variations.

Moschus maschiferus - only one species with several subspecies.

Flerov (1928) suggested three species -

Moschus maschiferus (Siberian)

Moschus chrysogaster (Himalayan)

Moschus berezovaskii (Chinese)

Groves (1975) recognized two species from India -

Moschus chrysogaster (Alpine)

Moschus sifanicus (Forest belt)

Distinctive features :

1. Small deer without antlers.
2. Head-body length 80-100 cm, height 50-70 cm and weight 13-18 kg.
3. In males upper canine long and extends below upper lip.
4. Ear large and rounded.
5. Rump higher than shoulders.
6. Hind legs are long and muscular, fore legs are short and weak.
7. Hairs long, coarse and bristle. Age related changes in hair coats and colorings are observed.

New born with short, dark brown, soft hairs and densely covered with yellowish or white spots. In winter the spots become less defined or absent.

8. Tail short and completely buried in the long hairs of the anal region.

9. Male deer possesses musk gland, present anteriorly to male genitalia.

10. Can be recognized by distinctive jumping movement- like kangaroo.

Distribution :

Musk deer has been recorded in at least 13 countries of Asia and Russian forest. In Asia it is found in the Southern slopes of Himalayas - India (Jammu and Kashmir, Himachal Pradesh, Uttar Pradesh, Uttaranchal, Sikkim, Andhra Pradesh), Pakistan, Nepal, China, Bhutan, Tibet, Burma, Korea, Russia, Vietnam.

Habitat preference :

Musk deer prefers rugged terrain between 2200-4000 m. altitudes and occupies both alpine and forest belt. Sections with rock outcrops is their favourite habitat which provide shelter from predator.

Food habit :

Feeds mainly on grasses, herbs, mosses, ferns, arboreal lichens (130 types). In winter generally takes arboreal lichens, terrestrial bushy lichens (70%); also eat young shoots, coniferous needles, leaves, buds and bark. In summer feeds upon herbaceous plants.

Breeding Habit :

Female deer attain sexual maturity within 16-17 months and males after 2-3 years. Estrus occurs during December-January and lasts for 3-4 weeks. Gestation period inbetween 185-195 days. Generally fawns one, rarely two at selected places - beneath dense shrubs, under low branches of fir, around fallen trees in between April-June.

Behavior :

They are shy and secretive animal and active at twilight or at night. Normally moves solitary - highly territorial or in groups of 2-3. Vision and hearing are keen but sense of smell is poor. The musk pouches releases a scent which attracts mate. Also shows migratory behaviour from Steep Mountain to grassy meadows near river valley.

Economic importance :

1. Musk deer are hunted for centuries for their musk. Musks are highly priced in Traditional Medicine (90%) and are used in more than 400 preparations for heart and nervous disorders. Remaining 10% are used in perfume industry.

2. One kg musk costs about 1,00,000 DM ($ 40,000- 50,000) i.e. Five times more than the price of gold.

3. For extracting 1 kg of musk it needs 40 males (approximately 160 specimens) on an average of 25 mg musk per male.

4. During the years 1857-58 Japan imported 1 lac sacs in a single year

5. In 1995-97, 1.5 tonnes of musk exported from Russia to Korea.

Present status :

1. Their timid nature and remote habitat makes a constrain for population to estimate; once a widespread species now become restricted to isolated pockets, assuming a global population of 4-8 lac.

Regional population about 30,000 and shows a declining trend at suspected reduction rate 20% per year. Russian population has reduced to half of its size in the last ten years.

2. National Status (1994) - Vulnerable (RDB), Critically Endangered (1997).

3. International Status (1996) - Lower Risk group.

4. CITES - Appendix I.

5. IWPA (1991) - Schedule I, Part- I.

Threats to survival :

1. Due to indiscriminate persecution throughout its range.

2. Destruction of habitat and livestock grazing inhibits natural regeration.

3. Predated by leopard, marten, wolf, lynx and remains in 43% in lynx's feces.

4. Because of small size, musks are easy to hide and transport thus making smuggling easier.

Conservation strategy :

1. Captive population kept in

- Himachal Pradesh Musk deer farm (Kufri)
- Dachigram Sanctuary (Kashmir)
- Padmaja Naidu Himalayan Zoological Park in Darjeeling.

2. One breeding enclosure is present at Kedarnath sanctuary; breeding and extraction done at Kufri (1975).

3. Enlisted in IWPA (I) & CITES (Appendix I) - thereby fully protected from killing and trade.

4. Sanctuaries and National parks on its distribution range will help to restore habitat.

5. Introduction of synthetic product allied to musk will reduce the demand for natural product.

6. International trade must be prohibited by increasing vigilance on smuggling.

7. In situ conservation should be encouraged.

8. Education and research on this dwindling species should be promoted.

14.2 Manipuri Brow Antlered Deer (SANGAI) *(Cervus eldi eldi)*

Taxonomic Position :

Order : Artiodactyla.

Family : Cervidae.

Distinctive features :

1. Sangai is a beautiful deer having height at shoulder 105-120 cm. and weight- 170 kg.
2. The male deer has a dark brown winter coat which turns to fawn in summer; the female is fawn all year round. The young are spotted.
3. Sangai has splayed hooves and long dewclaws.
4. Hind pasterns greatly developed and applied to the ground while walking.
5. Keen eyesight and speed allow it to be an open ground deer.

Distribution :

Sangai is Endemic to India and confined to Manipur (Loktak Lake) in Keibul Lamjao National Park which is less than 10 sq km area. The number of mature individuals is less than 100 (Gee, 1960) while the captive population consists of 94 individuals in 14 zoos.

Habitat preferences :

Sangai prefers open scrub jungle, flat or undulating lands between hills and river range (floating swamps called Phumids) and also marshy lands.

Food Habit :

Sangai is terrestrial in nature and lives in small herds and feeds mainly in the morning and evening mainly on grass.

Breeding habit : very little is known about its breeding behaviour.

Behaviour : This deer walks on hind surface of its pasterns, which are thus horny and not hairy. It moves with mincing hops over floating foliage and is also called 'Dancing Deer'. It is known to raid crops at night. A sharp grunt indicates alarm, while rutting calls are longer and louder.

Present Status :

It is declared Critically Endangered in the IUCN Red List.

It lives in a single population only in one location.

Globally - data deficient.

CITES - Appendix I ; Schedule - I; Part - I.

Threats to Survival :

1. Endemic to India, a single population present only in one location which is extremely regional.

2. Gradual decline in area of occupancy due to human settlement, interference, cattle grazing, damming, fishing, hunting and cultivation. Loss of habitat by siltation, burning of grass are also responsible.

3. Trade, diseases, genetic problems are among the other reasons of their declination.

Conservation strategy :

1. No reliable census has been done (Aerial Census only Desai, 1986 ; Forest Department data '94-'97)

2. No genuine Stud Book has been prepared.

3. Proper monitoring limiting factors should be done.

4. Habitat and genetic management are necessary.

5. Enhanced allocation of fund and stuff.

6. Captive breeding and reintroduction programmes are necessary to maintain the wild population.

UNIT 15 ❑ Wildlife Habitat Management with Special Reference to Sundarban

Structure

15.1 Wildlife Management in Sundarban

15.2 Threats to Mangrove Ecosystem

15.3 Current Management Practices

15.1 Wildlife habitat management in sundarban

Area :

The Sunderbans is the largest prograding deltaic region of the world. It extends through India to Bangladesh, covering a total area of about 26000 square kilometers - the largest single stretch of mangrove vegetation. About two-third of the total Sunderbans falls in Bangladesh. The Indian Sunderban measures 9630 square kilometers, out of which the Reserve Forest occupies around 4263 sq. km and the South 24 Parganas Forest Division Area occupies 1660 square kilometers. The administrative boundary is spread over two districts : South 24 Parganas and North 24 Parganas.

Latitude : 21°32 minutes and 22°40 minutes north.

Longitude : 88°30 minutes and 89° east.

Status :

At the launch of **"Project Tiger"** in the year 1973, the Sunderbans was among the nine Wildlife Reserves declared as **'Tiger Reserves'** (a total area of 2585 square kilometers). Within Sunderban Tiger Reserve, an area of 1330.12 square kilometers is designated the 'Core Area' which in the year 1984 was declared the **'Sunderban National Park'**. The rest of the area is the 'Buffer Area', part of which in the year 1976 was declared the **'Saznekhali Wildlife Sanctuary'**. In the year 1987 due to "high biodiversity" and "ongoing geological processes" Sunderbans National Park was declared a **'World Heritage Site'** by IUCN. The Sunderbans also achieved a milestone in 1989 when UNESCO declared it a **'Biosphere Reserve'**. The process of declaring it a **'Ramsar Site'** for being an outstanding wetland is in an advanced stage.

Climate :

Average annual temperature is 25°C.

Summer : middle of March to middle of June; maximum average temperature 29°C.

Winter : December to February; maximum average temperature 20°C.

Rainfall : average annual rainfall is about 192 cm. The rivers become calm between December and February.

Principal Rivers :

River Hooghly along with its tributaries and distributaries like Matla, Icchamati, Raimongol, Bidyadhari, Kalindi, Guasabha, Saptamukhani, Thakuran and innumerable crisscrossing channels and creeks forms the unique riverine system of this area.

The rivers of the Indian Sunderban carry much less silt and sweet water in comparison to those of the Bangladesh Sunderbans. Consequently they drew more seawater inside. Moreover, due to bulk drainage of water from the Hooghly river system to the Padma River in Bangladesh, the freshwater rivers like Matla and Bidyadhari do not get much fresh water and have become almost tidal rivers. Due to influx of sea water the salinity is intense and it has a threatening impact on the mangrove community.

Flora :

The mouth of the tidal creeks and rivers, where salt and fresh water mix in ideal proportions, show the greatest concentration of mangroves in the Indian Sunderbans. A total of 84 species of flora have been recognized in the mangrove forests of the Indian Sunderbans of which 34 are true mangroves. The other varieties are mangrove associated and back mangrove species. Another fact adds to the unique richness of this mangrove delta - it is home to 70% of all the species of mangrove in the world. As they are mostly restricted to inter-tidal belts at the land-sea interface, the mangroves here are exposed to high and low tides twice in 24 hours.

The mangroves have the ability to maintain a suitable water balance in spite of the salinity of water. It is believed that some even excrete salts from their leaves. The anchoring mechanism of the trees baffles even the most expert navigators. The roots are modified so that they can stand firmly in the mud. They spread horizontally as prop roots just below the surface of the mud and provide the necessary anchorage (e.g. - Garjan). This helps the trees in withstanding cyclonic weather and soil erosion. Since the aeration of the clayey soil is very poor, some trees have evolved special aerial roots whose tips protrude out of the mud upwards like spikes called 'pneumatophores' or commonly called respiratory roots (e.g. - Keora). They ensure sufficient supply of oxygen to the deeper roots. But accumulation of silt raises the mud banks continually thereby increasing the anaerobic zone. The growth of these pneumatophores has to keep pace with the raised water level. For the same reason, some roots of trees arching here and there above the surface of mud like knees (e.g. - Kankra).

The mangroves are extremely skillful in colonizing newly created mud banks. The future roots of the plant extend upto a length of 30 cm or more before they get detached from the parent plant. Eventually, when they fall, they are driven like stakes in the mud below the parent tree. Sometimes they are carried away by the water and strike root elsewhere. This is scientifically known as 'viviparous germination' (e.g. - Kankra).

The mangroves play an important role in the delta :

- They produce economically significant product like timber, firewood, honey, wax, tannin and other medicines.
- They produce leaf litter and debris which fulfill the nutritional requirements of the young prawns, adult shrimps, mollusks and fish of high economic value.
- They act as the breeding and feeding ground of shell fishes and fin fishes.
- They also protect the coastal land from storms, surges, tropical cyclones, high winds etc.
- The Sunderbans mangrove swamp is home to the single largest tiger population of the country.
- It protects the human settlements and even metropolitan Kolkata from the frequent gales originating in the Bay of Bengal.

SOME COMMON PLANT SPECIES

Common Name	Scientific Name	Family
Bakul	*Bruguiera cylindrical (L) Blume*	Rhizophoraceae
Sundari	*Heritiera fomes Buch-Ham*	Sterculiaceae
Bhola	*Hibiscus tilliaceous L*	Malvaceae
Golpata	*Nypa fruticans Wurmb*	Palmae
Hental	*Phoneix paludosa Roxb*	Palmae
Keya	*Pandanus tectorius soland*	Pandanaceae
Garjan	*Rhizophora apiculata Blume*	Rhizophoraceae
Keora	*Sonneratia apetala Buch-Han*	Lythraceae
Harguja	*Acanthus ilicofolius L*	Acanthaceae
Kankra	*Bruguiera gymnorhiza (L) Lam*	Rhizophoraceae
Nona jhau	*Tamarix troupii Hole*	Tamaricaceae
Hodo	*Acrostichum aureum L*	Pteridaceae

Fauna :

Marine Invertebrates :

The best season to observe marine life in the Sunderbans is from November to April, when the salinity of the water rises. The diversity of marine life is best explored at low tide, when the mudflats of the mangrove swamp or sandy beaches of Ganga Sagar and Bakkhali are exposed.

During the months of January-February the most exhilarating sight is of the migration of the thousands of jelly-fish swooping into the green waters of the rivers of the Sunderbans. Animals found on the rocky shores are Acorn barnacles, Sea anemones, Oysters, Periwinkles etc. The sandy shores of Sagar or Bakkhali seem barren at first sight as the inhabitant here mostly live beneath the surface. However, the evidence of their presence is seen in the typically designed sand or mud palates at the mouth of the animals' hole. Hermit crabs are abundant. Also sea-pen, polychaetes, ribbon worms, Telescopium, Wedge clams are common on the beach.

The Sunderbans has an immense diversity of crabs. Some of them are colourful, others dull. Sandy beaches of the far south are full of Ghost crabs which are deep red in colour. Red and yellow fiddler crabs are also very bright and colourful creatures. Among the edible varieties, Mud crabs are tasty and have good international market. The other important variety is the Horse-shoe crab which is a highly endangered species.

Fishes :

The rivers of the Sunderbans harbour hundreds of species of fish. Most of them are edible. A large number of people living on the edge of the forests are dependent on fishing for their livelihood. Some of the fishes are of high commercial value, such as Hilsa, Bhetki, Pomfret, Topse and Parse. Other tasty fish include Kanmagur, Paira Chanda, Gangdhara, and Bombay duck. Among many species of shell fishes, prawn (Bagda) and shrimps (Chapra) are the most important commercial varietie

COMMON ELASMOBRANCHS	
Common name	**Scientific name**
Bamboo shark	*Chiloscyllium sp.*
Tiger shark	*Stegostomata sp.*
Whale shark	*Rhinchodon sp.*
Hammer-headed shark	*Sphyrna sp.*
Pointed saw fish	*Pristis cuspidates*
Sting ray	*Dasyatis sp.*

MAJOR TELEOSTS FISHES	
Common name	**Scientific name**
Khaira	*Sardinella sp.*
Hilsa	*Hilsa ilisha*
Bombay duck	*Harpodon nehereus*
Kanmagur	*Plotosus canis*
Parse	*Mugil parsia*
Bhangan	*Mugil tade*
Topse	*Polynemus padiseus*
Bhetki	*Lates calcarifer*
Paira Chanda	*Scatophagus argus*
White Pomfret	*Chondropites chinensis*
Ban	*Mastocembelus armetus*
Moray eel	*Gymnothorax favagineus*
Bele	*Sillago sihama*
Chanda	*Pama pama*

Birds :

The unique ecosystem of the Sunderbans is very rich in avian or bird life. Over 200 species of birds have been recorded so far. The species vary from forested areas to villages, from mangrove swamp to estuaries and all canopies to mudflats.

The highest canopies of the forests are occupied predominantly by Osprey, Brahminy kite and White-bellied sea eagle which are raptors or bird of prey. The middle tier of tall trees is the nesting, perching and feeding place of birds like Rose-ringed parakeets, small bird like flycatchers, warblers, Small minivets, bee-eaters and tree creepers like Golden-backed woodpeckers and the wryneck. Other birds include orioles and barbets. In the lowest tier there is predominance of kingfishers. The Sunderbans harbours seven species of kingfishers, namely - White-breasted, Pied, Common blue, Black-capped, Collared, Brown-winged and Ruddy kingfishers.

The mudflats are full of waders, during the low tide. Waders include the Common sandpipers, Terek sandpipers, Redshank, Greenshank, White-breasted waterhen and others. The most typical birds of the muddy riverbanks are the curlew and whimbrel. Lesser adjutant storks are the largest storks of the Sunderbans. Open-billed storks are found near cultivation. Large egrets add beauty to the serene landscape of the Sunderbans. The Pond herons are most common of al herons. Grey and Purple herons are also seen but they are rare. The rarest of all herons is the Goliath heron.

Ducks come in thousands into the Sunderbans every winter. Gadwalls, Pintails and Shovellers are common. But Wigon and Common pochards are not rare. Brown-headed and Black-headed gulls are found throughout the year. In recent times, rare birds like the Spoon-billed sandpipers, Mangrove pitta and Rosy pelican have been recorded.

Reptiles :

The estuarine crocodile is the largest reptile of the Sunderbans. Ornamental and vine snakes are common non-venomous snakes of the region. But in the villages of the Sunderban most deaths take place due to bite of common krait. The Indian cobra and Russell's viper are among the other most poisonous snakes of the region. The coastal sandy beaches of Mechua, Chaimari, Kalash and Bijeara are the nesting grounds of the Olive Ridley turtles. Among fresh water species, one of the most endangered turtles, *Batagur baska*, is found in the Sunderbans.

TURTLES, TORTOISES, TERRAPINS

Common name	Scientific name
River Terrapin	*Batagur baska*
Green Turtle	*Chelonia mydas*
Olive Ridley Turtle	*Lepidochelys olivacea*

SNAKES

Common name	Scientific name
Common Checkered Keel back	*Xenochrophis piscator*
Rat Snake	*Ptyas mucosa*
Common Krait	*Bungarus caeruleus*
Banded Krait	*Bungarus fasciatus*
Indian Cobra	*Naja naja*
Russell's Viper	*Daboia russelli*
Ornamental Snake	*Chrysopelea ornate*
Sea Snake	*Hydrophis nigrocinctus*
Green whip Snake	*Ahaetulla nasuta*
Wolf Snake	*Lycodon aulicus*

LIZARDS & CROCODILES	
Common name	**Scientific name**
Tokay	*Gekko gecko*
Garden Lizard	*Calotes versicolor*
Chameleon	*Chameleon zeylanicus*
Water Monitor	*Varanus salvator*
Monitor Lizard	*Varanus flavescens*
Estuarine Crocodile	*Crocodylus porosus*

Mammals :

There is not much diversity in the mammalian species found in the Sunderbans. But, it can boast about its Royal Bengal Tigers. Due to hostile ecological and riverine conditions, these tigers have evolved different habits from the tigers of other forests of India. They are good swimmers, drink saline water, are more hardy and agile and eat anything from fish to human beings. The major preys of the Sunderban tigers are wild boars and chital deer. The Sunderban is rich in aquatic mammals.

MAJOR MAMMALS OF THE SUNDERBANS	
Common name	**Scientific name**
Royal Bengal Tiger	*Panthera tigris tigris*
Fishing Cat	*Felis viverrina*
Rhesus Macaque	*Macaca mulatta*
Axis Deer or Chital	*Axis axis*
Indian Wild Boar	*Sus scrofa*
Finless Porpoise	*Neophocaend phocaenoides*
Gangetic Dolphin	*Platanista gangetica*
Smooth Indian Otter	*Lutra perspicillata*
Irawaddy Dolphin	*Orcaella brevirostris*
MAMMALS WHICH HAVE BECOME EXTINCT	
Common name	**Scientific name**
Javan Rhinoceros	*Rhinoceros sondaicus*
Swamp Deer	*Cervus duvauceli*
Wild Buffalo	*Bubalus bubalis*
Barking Deer or Muntjac	*Muntiacus muntjak*

People :

At present out of 108 islands, 54 are inhabited. The population is about 4.1 million (2001 census). A unique religious harmony among Hindus and Muslims is observed here. Monocropping, agriculture, fishing, prawn seed collection and manual labour are the major occupation.

15.2 Threats to mangrove ecosystem :

There are a number of causes that threaten the Mangrove ecosystems.

Increased Salinity: Due to a shift in the freshwater flow from the Hooghly River system into the Padma River, major freshwater rivers like Matla and Bidyadhari were cut off from their freshwater sources. Embankments have been constructed in the coastal zone to protect human settlement in some areas. As a result of this, the salinity of water has increased to an intense level, leading to a change in the mangrove pattern of the region. Saline banks have formed on the islands. The 'Sundari' tree has become endangered due to this excess of salinity in the water, whereas it flourishes in low salinity areas of the eastern part of the Bangladesh Sunderbans.

Sewage Pollution : Part of the sewage from the city of Kolkata, Howrah and Haldia Complex gets released continuously into the river water, polluting it. Moreover, release of oil and grease from adjacent land, fishing vessels, trawlers etc. also contribute to such pollution of the mangrove ecosystem. It has a long standing effect on the flora and fauna of the Sunderbans.

Cyclonic Destruction : During April-May and October the area is exposed to repeated cyclonic storms and depressions that destroy the flora among the coast. Besides every year the sea encroaches on a large portion of the mudbanks. The continuous destruction and re-formation of land has created instability in the natural vegetation pattern.

Prawn culture : Collecting shrimps and prawn seeds by the crude method of netting is a popular and profitable activity carried out by peoples of almost all age groups. These prawn seeds (larvae of *Peneus monodon*) are supplied to the commercial prawn culture firms. During this operation the juveniles of a large variety of fin-fish and shell-fish are also caught in the nets. After scrutiny they are simply thrown away and wasted. An investigation reveals some startling facts - juveniles of about 50 species of fin-fish and 28 species of shell-fish are wasted per net per day. This unsustainable activity has already placed a strain on the fishery of the state. The dragging of nets along the coast uproots the mangrove seedlings, leading to soil erosion in the coastal zone. Expansion of aquaculture, prawn farming, drying of sea-fish etc. thus create a direct threat to the existing mangrove forests.

Endangered Species : Many species like the tiger, fishing cat, Gangetic dolphin, adjutant stork, estuarine crocodile, Olive Ridley turtle etc. have already acquired the endangered status, due to habitat destruction, poaching, increased salinity, anthropogenic stress and illegal trade. The Horse-shoe crab - a living fossil - is killed and sold in the markets of Kolkata with a misplaced belief that it can cure arthritis.

Man-Animal Conflict : Extremely high human density (over four million) on the forests fringes results in extremely high biotic pressure such as fishing, illicit felling and prawn seed collection. Straying of tigers into villages along the western boundary of the Sunderbans Tiger Reserve and north-western fringes of 24 Parganas (South) forest division causes acute man-animal conflict which poses a direct threat to conservation effort.

15.3 Current management practices :

Protection :

Establishments of camps, watch towers covering all the remote areas.

Supply of improved fire arms to field staff, providing patrolling vessels and mobile patrolling camps.

Afforestation :

Afforestation of mudflats and outer slopes of embankments with pure mangrove species for bank protection and soil conservation.

Afforestation of inner slopes with fast growing and endangered species.

Distribution of seedlings for planting on private lands.

Habitat Development Activities :

Development of water holes.

Opening up canopy though construction of observation lines. Such measures also help the growth of herbivores.

Reduction of Man-Animal Conflict :

Straying of tigers from the Reserve Forests into the habitat areas along the Northern and Western fringes of Sundarban Forest causes occasional death of cattle or human as well as tiger. Illegal entry of fishermen into core areas, as well as entry of honey bee collectors into the forest also leads to death of a number of people. To prevent straying of tigers into village's nylon net, fencing, tranquilization and capture of straying animal and their subsequent release into the forest is practiced.

Eco-Development Measures :

Community development projects : Construction of irrigation canals, sweet water ponds, village brick paths, jetties, tube wells, embankments, organization of regular medical camps.

Individual beneficiaries oriented schemes : Apiary, mushroom cultivation, Piggery, vocational training for cottage industries etc.

Census :

Biennials census of tiger is carried out in December. The last census has been done from 7-14 Dec, 2001.

Monitoring :

Geographical Information System (GIS) cell has been developed under Sundarban Biosphere reserve has updated forests/vegetation and topography map of Sundarban as on March, 2001, using satellite imageries from IRS-1D. GIS based information and maps have been used for updating the management Plan of Sundarban Tiger Reserve.

Management of Sundarbans forests involves an integrated approach towards management of all the above aspects with a goal to conserve the fragile mangrove ecosystem for prosperity.

Further Research :

Facilitating research, monitoring, education and training to perpetuate the progress made by the management. For this the total area of the Biosphere Reserve has been divided into :

- Core zone covering approx 1700 sq km.
- Buffer zone
- Transition zone.
- Project Tiger :

The Sunderbans can, no doubt, boast about its tigers. It is home to the largest number of tigers in India and perhaps in the world. This has put the Sunderbans on the international tourism maps.

The Sunderbans was declared a Tiger Project in 1973, covering an area of 2585 square kilometers, of which 1330 square kilometers is the core zone and 1225 square kilometers is the buffer zone. The total land area of the Sunderban Tiger Reserves is more or less 1580 square kilometers and the total water surface is about 1005 square kilometers.

The Project Tiger is headed by the Field Director who is a conservator. His team includes a Deputy Field Director who is one of the ranks of a Divisional Forest Officer, an Assistant Field Director who is the rank of Additional Divisional Forest Officer and 12 Range Officers.

CENSUS									
YEAR	**24 Parganas (South) Division**				**Sunderban Tiger Reserve**				**Total Estimated Tigers**
	Male	**Female**	**Cub**	**Total**	**Male**	**Female**	**Cub**	**Total**	
1997	13	16	06	35	99	137	27	263	298
1999	09	16	05	30	96	131	27	254	284
2001	07	13	06	26	93	129	23	245	271
2004	07	14	04	25	83	133	33	249	274

SUGGESTIVE READINGS

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মানুষের জ্ঞান ও ভাবকে বইয়ের মধ্যে সঞ্চিত করিবার যে একটা প্রচুর সুবিধা আছে, সে কথা কেহই অস্বীকার করিতে পারে না। কিন্তু সেই সুবিধার দ্বারা মনের স্বাভাবিক শক্তিকে একেবারে আচ্ছন্ন করিয়া ফেলিলে বুদ্ধিকে বাবু করিয়া তোলা হয়।

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